THE UNIVERSITY OF ALBERTA

SPRAY RIVER FORMATION NEAR BANFF AND CADOMIN

A THESIS

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ABSTRACT

The two sections of the Spray River formation of the Triassic system, one near Banff and the other near Cadomin, Alberta were measured and sampled. The Spray River formation is divisible here into a Lower Triassic Sulphur Mountain member and a Middle Triassic Whitehorse member. The Sulphur Mountain member consists of dolomitic and calcitic siltstones, silty dolomites and dolomitic limestones and dolomitic very fine sandstones. The Whitehorse member is comprised of dolomites, dolomitic siltstones and limestones and dolomitic and calcitic orthoquartzites and protoquartzites.

Samples were examined in thin sections and grain mounts, X-rayed for dolomite/calcite ratios and analyzed for carbonaceous material and iron content. An attempt was made to correlate the two sections, to determine the provenance and to reconstruct the depositional history of the formation.

Two possible correlations have been suggested: one on the basis of change of angularity, which occurs near the Sulphur Mountain-Whitehorse contact, and the other on the quantitative relationship between tourmaline and zircon. The latter correlation agrees with the questioned position of this contact in Warren and Stelck's correlation.

At the time of deposition of the Sulphur Mountain member, the sediments were largely derived from a low and/or distant Pre-cambrian source, taken to be the Canadian Shield to the east. The Whitehorse member has greater sedimentary contribution and indicates a possible change of source.

The sediments were laid down in a shallow marine environment. The lower part of Sulphur Mountain member was deposited in a somewhat reducing environment below the action of the waves and in somewhat deeper water than the Whitehorse member, which was probably deposited above wave-base.

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INTRODUCTION

General Statement

The Spray River formation is the name given to the lower and middle Triassic deposits of the Alberta Foothills. It consists of thin-bedded, platy, calcareous or dolomitic siltstones, fine-grained sandstones and shales with a characteristic reddish brown weathering colour.

The Triassic in Western Canada assumed economic importance with the first discovery of a commercial gas field at Whitelaw in northwest Alberta in 1950. In 1951 and 1952 Triassic gas reserves at Tangent and Fort St. John were found, followed by the discoveries of significant accumulations of oil and gas in Triassic strata at the Boundary Lake, Buick Creek, Kobes Creek, Blueberry, and Milligan Creek fields in British Columbia and in the Sturgeon Lake region of Alberta. In addition gas was found in the Sulphur Mountain member of the Spray River formation in the Mountain Park area of Alberta.

The distribution of Triassic rocks in the southwestern, northwestern and eastern Cordillera is wide-spread and extensive. They are relatively restricted, however, under the western plains, extending only from the Rocky Mountain Foothills belt of northeastern British Columbia eastward to about 117° longitude in northwest Alberta and from approximately 54° to 59° north latitude, an area of nearly 55,700 square miles. According to Crockford and Clow (1953), no Triassic rocks have been recognised in any deep wells drilled in the southern Alberta foothills. In the Peace River region, they have been identified in

Southern Production's well number B-14-1 (Lsd. 1, Tp. 84, R. 23, W. 6th Mer.) and in Pacific Fort St. John well number 16 (Lsd. 12, Sec. 18, Tp. 84, R. 19, W. 6th Mer.), Hunt and Ratcliff (1959).

Triassic rocks also occur throughout the Front Ranges of the Rocky Mountain and parts of their adjacent Foothills. Good outcrops occur along the Grayling, Liard and Tetsa valleys, in the Peace River foothills, along Mowitch Creek (N.W. of Jasper Park), Whitehorse River (two miles south of Cadomin) and Spray River (near Banff).

McLearn (1953, p. 1207) points out that the Triassic rocks of Western Canada exhibit two contrasting types of development. In the eastern system of the Cordillera viz., in the Rocky Mountains and foothills and to some extent on the western border of the Plains, the formation consists mainly of calcareous sandstone, siltstone, calcareous siltstone, shale and some limestone. The Triassic of Western Cordillera, west of the Rocky Mountain Trench are associated with or include great thicknesses of volcanic rocks, correlative with the Nicola group.

Triassic faunas have world-wide distribution. For instance, the genus *Flemingites* is useful in correlating the Sulphur Mountain member of the Spray River formation with the outcrop Flemingites-beds in West Pakistan. The *Nathorstites* bearing Triassic beds of northeastern British Columbia may also be correlated with the South Asiatic succession particularly in the Himalayan realms on the site of the ancient Tethy's seaway.

Purpose and Methods of Study

The purpose of this study was to learn as much as possible of the provenance and depositional environment of the Spray River formation

by examining in detail the lithology and composition of a section near Banff and comparing it with a section farther north near Cadomin.

The locations of the two sections are as follows (see fig. 1):

1. Banff ------ at confluence of Spray and Goat Rivers

   Latitude --- 51° 06' 30" North

   Longitude -- 115° 29' 55" West

2. Cadomin ---- Along railway cut near confluence of McLeod and Whitehorse Rivers

   Latitude --- 52° 59' 00" North

   Longitude -- 117° 20' 15" West

The sections were measured stratigraphically upwards using a 5-foot staff, a 100-foot tape and a Brunton compass. Samples were collected as far as possible to represent lithologic variations; where the section was uniform over a few hundred feet, sampling was done at intervals of 30 to 40 feet; where the changes in lithology occurred over smaller intervals closer sampling was employed.

Samples collected were studied in the laboratory by the following methods:

1) Gravity separation of heavy accessory minerals with a heavy liquid.

2) Petrographic study by thin-section examination and grain immersion.

3) Determination of calcite-dolomite-ratios by X-ray techniques.

4) Determination of carbonaceous material and iron content by chemical analysis.

5) Search for microfossils.

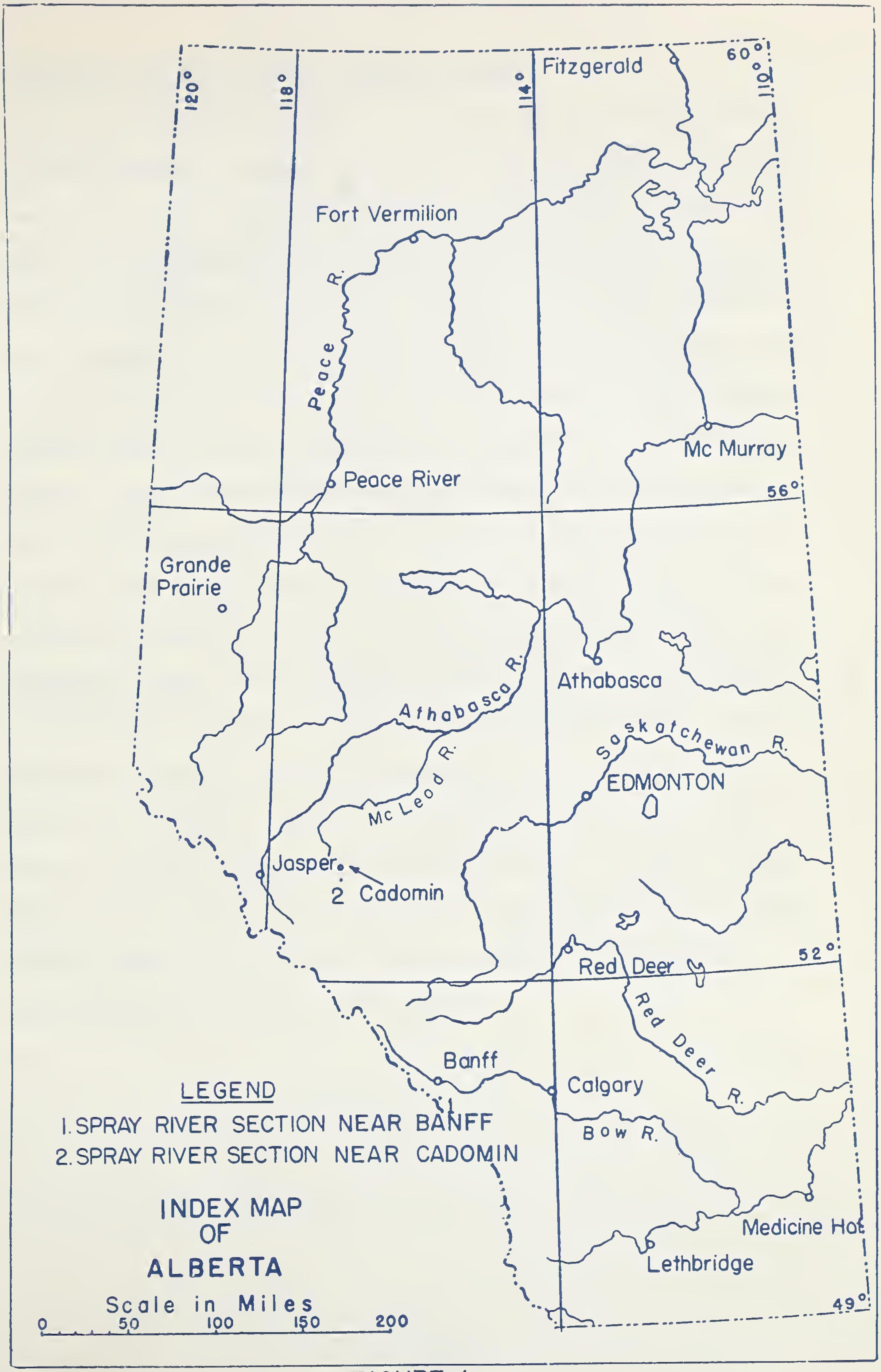

120°
118°
114°
110°
60°
56°
52°
49°
Fitzgerald
Fort Vermilion
Peace R.
Peace River
Mc Murray
Grande Prairie
Athabasca R.
Athabasca
Saskatchewan R.
EDMONTON
Mc Leod R.
Jasper
2 Cadomin
Red Deer
Red Deer R.
Banff
Calgary
Bow R.
Medicine Hat
Lethbridge
LEGEND
1. SPRAY RIVER SECTION NEAR BANFF
2. SPRAY RIVER SECTION NEAR CADOMIN
INDEX MAP
OF
ALBERTA
Scale in Miles
0
50
100
150
200

FIGURE 1.

Previous Work and History of Formation Names

R.G. McConnell (1887) called what are now the Spray River and Rocky Mountain formations of the Bow Valley the Upper Banff Shales and included them in the Carboniferous. Dowling (1907) separated the Rocky Mountain Quartzite from the Upper Banff Shales and placed the remainder of the Upper Banff shale sections in the Permo-Triassic, but Girty assigned it a Lower Triassic age after examining fossils collected by E.M. Kindle, L.D. Burling and H.W. Shimer (Lambe, 1916). Kindle (1924) proposed the name "Spray River formation" for this Triassic strata. This name was adopted by Warren (1927) in his monumental work "Banff Area, Alberta", and its use was further extended to the Mountain Park district by MacKay (1929) and to Jasper Park by Allan, Warren and Rutherford (1932). The terms Sulphur Mountain member and Whitehorse member were introduced for the Lower and Upper divisions respectively of the Spray River formation by Warren in 1945. Hunt and Ratcliff introduced terms for the Peace River area in 1959 for the sub-surface Triassic. They have retained the name Schooler Creek group, originally introduced by McLearn (1921) for a series of Upper Triassic sedimentary beds in foothills of northeast British Columbia, and sub-divided it into three formations, designated as Halfway, Charlie Lake and Baldonnel formations.

STRATIGRAPHY

General

The discussion of Triassic stratigraphy and correlation is confined here to occurrences in the eastern Cordillera.

In the Liard River area of northeastern British Columbia, the Grayling formation was first described by E.D. Kindle (1949). It consists of 600' to 1000' of marine soft laminated friable dark gray shale, with beds of hard ripple-marked sandstone, commonly one foot in thickness. The type section is located on the lower part of the Grayling River, a tributary of Liard River, where it rests probably disconformably on the Permian. It is dated Lower Triassic (Kindle, 1944; McLearn, 1945), and is very similar in appearance to the Sulphur Mountain member of the thesis areas. The overlying formation, known as the Toad formation (Kindle, 1944), of late Lower and early Middle Triassic age, consists of 800 feet to 1000 feet of dark calcareous siltstone, shale and limestone. It is correlative in part with the Whitehorse member of the thesis areas. The type locality is on Liard and Toad Rivers, near the mouth of Toad. The upper 600 feet of thicker-bedded gray calcareous sandstone and some shale and siltstone beds were separated and named Liard formation by Kindle (1948). The type locality is on Liard River; equivalent strata are unknown within the writer's study area. The Liard is overlain disconformably by the Lower Cretaceous Garbutt formation.

In the Peace River foothills, the Triassic is exceptionally fossiliferous and is more than 2500 feet thick. The occurrence of

Triassic here was first recognized by Selwyn in 1875. In 1908 investigations were resumed by McLearn and the name Schooler Creek was proposed by him in 1921 for the series of Upper Triassic sedimentary beds in the Peace River Foothills. The Triassic here is divisible in three main lithological units. The basal "Dark Siltstone", a provisional name proposed by McLearn (1947a), consists of 75 to 450 feet of marine dark calcareous shale, siltstone and dark lenticular limestone of probable Ladinic (late Middle Triassic) age. Above the "Dark Siltstones" are the "Gray beds", again a provisional name assigned by McLearn (1947b). These are massive calcareous sandstones and gray limestones about 2000 feet thick. They are late Middle to early Upper Triassic in age. Overlying the "Gray beds" conformably are the Upper Triassic Pardonet beds (McLearn, 1940), of Karnic and Noric age, consisting of dark calcareous shale and siltstone ranging in thickness from 250 to 2000 feet. Of the Schooler Creek beds, only thin remnants of the Pardonet beds are known in the writer's study areas.

On Mowitch Creek, northwest of Jasper Park, in the eastern part of the Rocky Mountains, Allan (1933) described the occurrence of red beds and gypsum, overlain by yellow to buff weathering shales and gypsiferous beds, followed by a Jurassic sequence. This has been interpreted by McLearn (1953) as a probable shore phase of the Triassic sea.

The Triassic beds in the southern and central Alberta Rocky Mountains and foothills are known as the Spray River formation. Warren (1945) divided the Spray River formation into a lower Sulphur

Mountain member and an upper Whitehorse member. The former is named after Sulphur Mountain near Banff and the latter name is derived from the Whitehorse River, a tributary of the McLeod River, near Cadomin, where this member is a distinctive unit. Warren (1927) designated as type section for the Sulphur Mountain member the section of Triassic rocks outcropping along the Spray River gorge at the south end of Sulphur Mountain, about ten miles south of the town of Banff.

Lithology of Measured Sections

The total measured thickness of the Spray River section exposed near Banff is 1537 feet, the Sulphur Mountain member makes up 1318 feet and the Whitehorse member 219 feet.

The Sulphur Mountain member consists of medium light gray (N6)* to dark gray (N5) and bluish gray (5B7/1, 5B5/1), calcitic or dolomitic siltstones to fine-grained sandstones, and dark gray (N3) to brownish gray (5YR4/1) shales. Siltstone is the dominant type of rock, the sandstone and shale being subordinate to it. In the siltstones, the carbonate and silicate content is usually nearly equal. Some are by strict definition limestones or dolomites, but because of similarity in appearance, they have all been here designated as "siltstone". The siltstones and sandstones occur commonly in well-defined, very thin to thin beds. The lower part of the Sulphur

* Code numbers from Rock-Color Chart, 1951.

Mountain member becomes thick-bedded. Both the sandstones and siltstones are usually slabby to platey and rarely blocky. [Bedding and splitting terms used are adapted from McKee and Weir (1953), see table 1, page 10].

The siltstones have fine distinct or vague laminations or cross-laminations, due to partings of carbonaceous material and/or pyrite. They are calcareous or dolomitic, micaceous and argillaceous. They are interbedded with shale, which is laminated to thinly laminated, fissile, calcareous or dolomitic. The rocks are well-cemented with carbonate so that when struck with a hammer, they give a phonolitic ring and often break with a conchoidal fracture.

Unlike the Sulphur Mountain member, which is recognized in outcrop by its rusty-brown weathering habit, the overlying Whitehorse member is characterised by weathering white. It is comprised of dolomites, limestones and calcareous or dolomitic sandstones. The limestones and dolomites are light gray (N7) and light (5B7/1) to medium bluish gray (5B5/1), thin to thick bedded, flaggy to blocky, occasionally with vuggy porosity. The sandstones are light olive gray (5Y5/2) to grayish yellow (5Y8/4), very fine to medium-grained, thin to thick bedded, flaggy to blocky, compact.

The Spray River section measured near Cadomin lies about 145 miles north-northwest of the section near Banff. The formation here is thinner than at Banff, totalling 824 feet. Warren's (1945) two members, viz., Sulphur Mountain and Whitehorse, are readily identifiable here.

The Sulphur Mountain member is 524 feet thick and consists

THICKNESS AND SPLITTING NOMENCLATURE

OF STRATA

TERMINOLOGY FOR STRATIFICATION		TERMINOLOGY FOR CROSS-STRATIFICATION		THICKNESS	TERMINOLOGY FOR SPLITTING
Very thick bedded	BEDS	Very thickly cross-bedded	CROSS-BEDDING	$>$ 4 ft.	Massive
Thick bedded		Thickly cross-bedded		2-4 ft.	Blocky
Thin bedded		Thinly cross-bedded		2 in.-2 ft.	Slabby
Very thin bedded		Very thinly cross-bedded		1/2 in.-2 in.	Flaggy
Laminated	LAMINAE	Cross-laminated	CROSS-LAMINAE	1/10 in.-1/2 in.	Platy
Thinly laminated		Thinly cross-laminated		$<$ 1/10 in.	Papery

TABLE 1

(After McKee & Weir, 1953)

of very light gray (N8) to medium bluish gray (5B5/1), medium to coarse siltstones and very fine to fine sandstones. Siltstone is the dominant type of rock. The siltstones and sandstones bear a great deal of similarity to those of the Sulphur Mountain member near Banff. In the siltstones, the ratio of carbonate to silicate content is nearly one to one.

The overlying Whitehorse member contrasts sharply with the Sulphur Mountain member. It is about 300 feet thick and is composed of siltstones, sandstones and dolomites. Siltstones are light bluish gray (5B7/1) to pale red purple (5RP6/2), medium to coarse-grained, sandstones are very light gray (N8), fine to very fine-grained. Dolomites are light bluish gray (5B7/1).

The three rock types occur in thin to thick beds, the splitting being flaggy to blocky. They are generally dense, hard, dolomitic, rarely calcareous, with occasional pin-point vugs, and are similar to the rocks of the Whitehorse member at Banff.

The detailed lithologic descriptions of the Spray River sections at Banff and Cadomin are presented in Appendix A.

Correlation of the Sulphur Mountain member of the Banff region with Grayling formation of Liard River section is considered established.

According to Warren (1945, p. 488) "The fauna so far collected and identified from the Whitehorse member of the Spray River formation is definitely early Middle Triassic in age." This makes the Whitehorse correlative with the Toad.

The stratigraphic relationship of the various sections of the

Triassic formations of Western Canada, including the two measured by the writer, as adapted from Warren and Stelck (1945), is illustrated in table 2.

The Spray River sections measured near Banff and Cadomin are disconformably overlain by the Jurassic Fernie group.

In regard to the lower boundary, Warren (1945, p. 483) states "Where a normal section is present, the Spray River formation lies apparently conformably on the Rocky Mountain Quartzite of Pennsylvanian and Permian? age. Although there is undoubtedly a time break represented at the base of the Spray River, there is no discrepancy in the dip of the two contiguous formations. In the northern extension of the Spray River formation, in the neighbourhood of Cadomin, the Rocky Mountain Quartzite has a more limited lateral extent than the Spray River beds, and the latter formation is found lying directly on the Mississippian Rundle limestone".

The writer's observations in the field are in complete accord with the above views. The lack of a readily apparent unconformity between the Paleozoic and Mesozoic is notable. To explain this apparent conformable contact between the two eras, one may perhaps have to assume that the region was a neutral area that was not being greatly affected by either erosion or by deposition during the time interval that is represented by the hiatus. It is difficult, however, to visualise such neutral conditions persisting over such a long period.

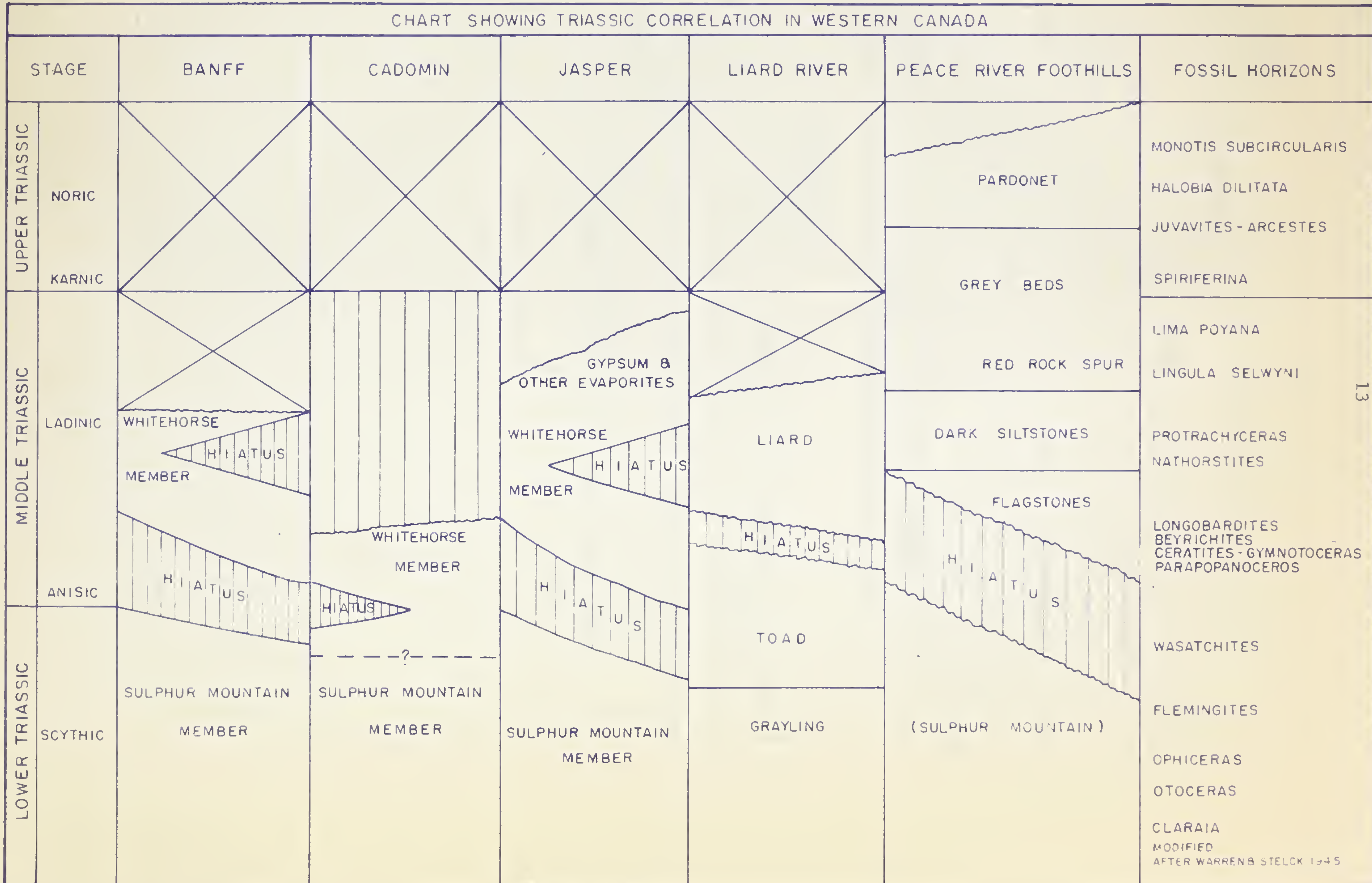


CHART SHOWING TRIASSIC CORRELATION IN WESTERN CANADA
STAGE
BANFF
CADOMIN
JASPER
LIARD RIVER
PEACE RIVER FOOTHILLS
FOSSIL HORIZONS
UPPER TRIASSIC
NORIC
KARNIC
MIDDLE TRIASSIC
LADINIC
ANISIC
LOWER TRIASSIC
SCYTHIC
WHITEHORSE MEMBER
HIATUS
HIATUS
SULPHUR MOUNTAIN MEMBER
WHITEHORSE MEMBER
HIATUS
?
SULPHUR MOUNTAIN MEMBER
GYPSUM & OTHER EVAPORITES
WHITEHORSE MEMBER
HIATUS
HIATUS
SULPHUR MOUNTAIN MEMBER
LIARD
HIATUS
TOAD
GRAYLING
PARDONET
GREY BEDS
RED ROCK SPUR
DARK SILTSTONES
FLAGSTONES
HIATUS
(SULPHUR MOUNTAIN)
MONOTIS SUBCIRCULARIS
HALOBIA DILITATA
JUVAVITES - ARCESTES
SPIRIFERINA
LIMA POYANA
LINGULA SELWYNI
PROTRACHYCERAS
NATHORSTITES
LONGOBARDITES
BEYRICHITES
CERATITES - GYMNOTOCERAS
PARAPOPANOCEROS
WASATCHITES
FLEMINGITES
OPHICERAS
OTOCERAS
CLARAIA
MODIFIED AFTER WARREN & STELCK 1945

TABLE 2

Fossils

(a) Microfossils:

The shale samples collected from the Spray River formations both from Banff and Cadomin areas were examined for microfossils. The samples for this study were prepared in the following manner: each shale sample was placed in a bottle containing tap-water for three to four weeks for disintegration. The sample was then washed through a series of U.S. Standard Sieves of 45, 60, 80 and 100 mesh. Each sieve fraction was dried and retained for picking. Standard picking technique was used. No identifiable microfossils were found.

(b) Macrofossils:

A specimen of the pelecypod species *Claraia stachei* (Bittner) identified by Dr. P.S. Warren in the field, was collected by the writer from the lower part of the Sulphur Mountain member of the Spray River formation at Banff. Occurrence of the same species throughout beds of the Grayling formation has been recorded by Kindle (1944).

PETROGRAPHY

A. Thin Section Study

Introduction

Thin sections were prepared for examination from 35 outcrop samples collected from the two sections measured. Of twenty samples from the Banff section, seventeen belong to the Sulphur Mountain member, and three to the Whitehorse member; of the fifteen samples from the Cadomin section, seven represent the Sulphur Mountain member and the remaining eight, the Whitehorse member. The thin sections were prepared by Mr. Arthur N. Johnson, Thin Section Laboratory, Pittsfield, Mass. The thin sections are described in detail in Appendix B.

Banff Area

Sulphur Mountain Member: Thin section study reveals that this member consists of dolomitic and calcitic siltstones, silty dolomites and dolomitic limestones and dolomitic very fine sandstones. In the dolomitic or calcitic siltstones and in the silty dolomites, the silica content and the carbonate content are very nearly equal; the same rock might be called a silty dolomite by an observer and a dolomitic siltstone by another. The lithologic term dolomitic limestone as used here means a rock containing more than 50% carbonate of which 10% to 50% is dolomite and 50% to 90% calcite. The distinction between calcite and dolomite in all samples was based on X-ray patterns obtained, as described in Appendix C.

The average grain size of the silt component and the sand component of the siltstone and sandstone is 0.05 mm. and 0.12 mm. i.e. coarse silt and very fine sand respectively (Lane et al., 1947). Twelve samples are coarse siltstones and five very fine sandstones. The very fine sand grains are angular to sub-angular, whereas the coarse silt grains are usually very angular to angular. This is probably due to the fact that the smaller the grain size the more slowly are the grains rounded by abrasion .

The rocks invariably are poorly sorted, well-cemented and loosely or occasionally moderately packed.

The principal detrital component of the rocks is quartz. It ranges from 40 % to 50% in twelve samples, 25% to 30% in four and makes up only 10% of one sample. The grains commonly show one detrital contact and occasionally two, but usually are completely separated by the carbonate in the rock. By far the greatest proportion of quartz shows sharp extinction and is probably of igneous origin. Grains showing undulatory extinction and therefore likely to be of metamorphic origin are a very minor constituent.

Carbonaceous material is present to the extent of 8% to 10% (by volume) in seven samples and from 3% to 9% in remaining ten samples. The fine laminations or cross-laminations seen in hand-specimens are due to concentration of carbonaceous material on bedding planes.

The heavy accessory minerals of the two sections have been described separately.

The matrix consists of clay minerals, and amounts to less

than 10%.

Next to quartz, carbonate is the most abundant constituent and is found in all the samples. In four specimens it amounts to 50% to 65% and in one to 75%. In the remainder it ranges from 35% to 40%. Porosity is very low never exceeding 3%.

Whitehorse Member: This member is comprised of calcitic dolomite, dolomite and calcitic orthoquartzite (Pettijohn, 1954). Calcitic dolomite and dolomite have detrital quartz, very fine to coarse silt size, sub-angular to angular and makes up only 5% of the rocks. The carbonate content is 92% to 94% and consists of both calcite and dolomite. The dolomite has a porosity of 5%, but the calcitic dolomite has no pore space.

Calcitic Orthoquartzite: It is a very fine to fine grained (average grain size being 0.13 mm.), rather poorly-sorted, loosely packed rock here, with 1% to 2% porosity.

The chief detrital constituent is quartz, which makes up 45% of the rock. It shows a wide range of angularity, the grains commonly being sub-angular to sub-rounded and very rarely well-rounded. About one-half the grains are frosted. Unstrained quartz is dominant; strained quartz makes up less than 5%. Irregular dusty inclusions are present but very minute and fairly rare. The grains are seldom in contact, being separated from one another by carbonate. The carbonate cement appears to have corroded the margins of some of the quartz grains.

The next most abundant detrital constituents are chert and

microquartzite, though both are very subordinate totalling only 2%. The grains are of very fine sand size and sub-angular. Matrix consisting of clay minerals amounts to 12% of the rock.

The carbonate cement is the second most abundant component making up 40% of the rock and being subordinate only to quartz.

Cadomin Area

Sulphur Mountain Member: Lithologically this member is silty dolomite, dolomite, dolomitic siltstone and dolomitic very fine sandstone. The rocks bear a close similarity to those of the Sulphur Mountain member at Banff in the proportions of carbonate and silica contents and in average grain-size and angularity of the quartz grains. The rocks, in general, as in Sulphur Mountain member at Banff, are loosely to moderately packed, poorly sorted, well-cemented with occasional low porosity. One of the dolomite samples has exceptional 15% porosity.

Quartz is the most abundant detrital component. It makes up 45% of the dolomitic siltstones and 20% to 35% of the silty dolomites. In the purer dolomites, however, it amounts to less than 1% of the rock constituents. Less than 3% of the grains show wavy extinction, characteristic of metamorphic quartz. Irregular dusty inclusions are present but very minute and rare. Detrital contacts are rare and when present are limited to one or occasionally two.

Carbonaceous material is present in six specimens from 1% to 6% by volume.

Matrix consists of clay minerals and ranges in amount from 7% to 10%.

Carbonate is present in all samples. In silty dolomites it varies in proportion from 45% to 60%; in dolomites from 97% to 99%; in dolomitic siltstone and sandstone 40% and 35% respectively.

Pore-space is present only in three samples: dolomitic sandstone and silty dolomite have 3% and the one dolomite sample has 15%.

Whitehorse Member: This consists of silty dolomites, dolomitic siltstones, dolomites, dolomitic protoquartzite (Pettijohn, 1954) and dolomitic orthoquartzite (ibid, 1954).

In dolomitic siltstones, detrital quartz amounts to about 45% of the constituents of the rock, whereas the silty dolomites have a considerably smaller quartz content of from 10% to 20%. Dolomite has only 1% quartz. Grain size and roundness bear the same relationship as that of Whitehorse member of the section near Banff, i.e. of greater angularity with decreasing grain size. The bulk of the grains exhibit sharp extinction; grains with wavy extinction amounting to less than 2% or 3%. A low porosity of 2% to 4% is present in four samples; the rest have no porosity.

Interstitial matrix consisting of clay minerals is present in all samples, varying in amounts from 6% to 13%.

Carbonate is present in all samples and is one of the main constituents of the rocks. It varies in abundance in the silty dolomites from 65% to 73% and in dolomitic siltstones and dolomites makes up 40% and 98% of the rock constituents, respectively.

Dolomitic Protoquartzite: It has grain size of very fine sand, (average size being 0.10 mm) and is ill-sorted, moderate to loosely packed with low porosity.

Among the detrital constituents, quartz makes up the largest portion amounting to 30% of the rock. The average grain size is in the very fine sand range (0.085 mm), with wide range in angularity, from sub-angular to well-rounded. A large proportion of quartz is probably of igneous origin, strained grains making up less than 2%.

Chert and microquartzite are minor constituents amounting to only 3%. These grains are rounded to well-rounded. The grain size is very fine sand (average = 0.09 mm). Mudstone rock particles are the second most abundant detrital component, amounting to 20% of the rock. They are rounded to well-rounded, the average size (0.21 mm) being the fine sand range though a few grains reach medium to coarse sand size.

Interstitial matrix consists of clay minerals and makes up 14% of the rock constituents.

Carbonate cement amounts to 32% and appears to corrode some of the quartz grains. It has filled the pore-spaces and reduced the porosity to 2%.

Dolomitic Orthoquartzite: This rock is of very fine sand size, is well-sorted, loosely packed, well-cemented and has no porosity.

The chief detrital constituent is quartz, which makes up 45%

of the rock. The average size (0.11 mm) is in the very fine sand range and angularity of grains varies from sub-angular to rounded. Strained grains amount to less than 2%. Contacts between the grains are very rare; the grains being separated by carbonate cement.

Chert and microquartzite are present to the amount of 2%. They are of very fine sand size (average = 0.06 mm.) and are sub-angular to sub-rounded.

Interstitial matrix consists of clay minerals and amounts to 12% of the rock components.

Carbonate cement amounts to 40% of the rock and entirely occupies any original pore-space.

B. Studies of Heavy Detrital Minerals

Preparation of Samples

Eighteen samples were selected for the study of heavy accessory minerals, twelve from the section measured south of Banff and six from the one measured near Cadomin. Most of the rocks are of very fine sand to silt-size grains, and well-indurated. In order to disaggregate the grains, the samples were passed through a jaw-crusher and then through a pulverizer. The ground sample was sieved for 15 minutes using a set of U.S. Standard Sieve Series and a Ro-Tap. The fractions caught on 120, 170 and 230 mesh screens were retained, the coarser two fractions being later combined. The retained fractions were treated with cold 5% HCl in an attempt to dissolve calcite and dolomite without removing apatite. After standing for 25 hours, the acid was decanted and the sample thoroughly washed with water and dried. Prior to weighing, tromp iron and magnetite were removed with a strong hand-magnet.

For separation of heavy accessory minerals, a standard separatory funnel method, using tetrabromoethane (sp. gr. = 2.96) as the separating medium, was employed and the grains were mounted in aroclor (n = 1.66), on a glass slide. The weight percentage of heavy minerals in each sample was calculated. The heavy accessory minerals constitute 0.01% to 0.04% by weight of the Spray River rocks in Banff area and 0.05% to 0.1% of the Cadomin area.

All mounts were examined with a petrographic microscope

and thirteen were selected for determining relative percentages by counting 200 grains of non-opaques, wherever it was possible. The following heavy accessory minerals were identified:

Tourmaline

Zircon

Biotite

Chlorite

Hematite

Muscovite

Pyrite

Rutile

Sphene

Tourmaline Study

This mineral is one of the major constituents of all the heavy mineral residues separated from the Spray River formation. A detailed study of this mineral was undertaken with the hope of obtaining information useful for correlation and determining the source of the Spray River sediments.

Tourmaline occurs in six different colours with several shades in heavy mineral assemblages of both the areas. The principal colours are olive-brown, brown, yellowish-green, green, black and blue.

On the basis of angularity, the tourmaline grains were grouped into two types: (a) angular, euhedral probably first cycle grains; (b) rounded more or less spherical and anhedral, multicycle

grains. The distribution of tourmaline based on colour and angularity is shown in figures 2 and 3. As a rule, the smaller the grain size the more angular are the tourmaline grains. Inclusion of irregular globular, gas or liquid-filled cavities and very fine "dusty" types, were present regardless of colour variety.

The following observations were made from the study of tourmaline varieties:

(1) Among the main colour groups, three groups viz., olive-brown, brown and yellowish-green were common to the two members in both the areas.

(2) In the Sulphur Mountain member, the number of angular grains was much greater than that of the rounded grains in the colour groups common to the two sections (see figures 2 and 3).

(3) Within the Whitehorse member of the two sections, the rounded grains of the common colour groups out-numbered the angular grains.

(4) The Whitehorse member of both sections showed the presence of authigenic tourmaline, as a colourless overgrowth at one end of a detrital grain. No such development could be identified in the tourmalines examined in the heavy mineral assemblages separated from rocks of Sulphur Mountain member of the two sections.

Zircon Study

Zircon was the second most important mineral of the heavy accessory mineral assemblages examined from both areas. Three main varieties of zircon were distinguished on the basis of colour:

(1) pale red purple (5RP6/2) - this variety sometimes assumed a

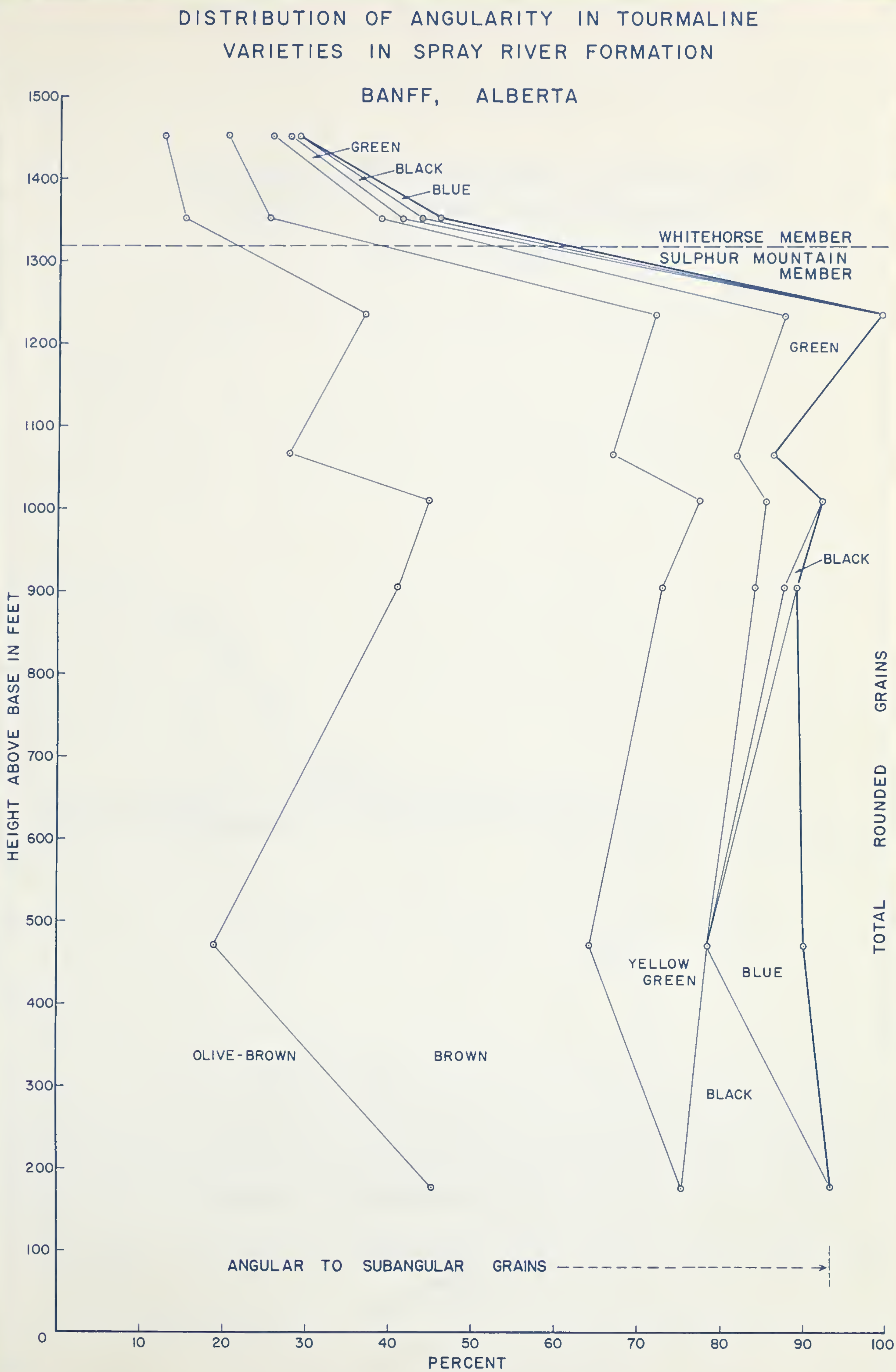

DISTRIBUTION OF ANGULARITY IN TOURMALINE
VARIETIES IN SPRAY RIVER FORMATION
BANFF, ALBERTA
HEIGHT ABOVE BASE IN FEET
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
GREEN
BLACK
BLUE
WHITEHORSE MEMBER
SULPHUR MOUNTAIN MEMBER
GREEN
BLACK
TOTAL ROUNDED GRAINS
YELLOW GREEN
BLUE
OLIVE-BROWN
BROWN
BLACK
ANGULAR TO SUBANGULAR GRAINS
10
20
30
40
50
60
70
80
90
100
PERCENT

Fig. 2

DISTRIBUTION OF ANGULARITY IN TOURMALINE VARIETIES IN SPRAY RIVER FORMATION

CADOMIN, ALBERTA

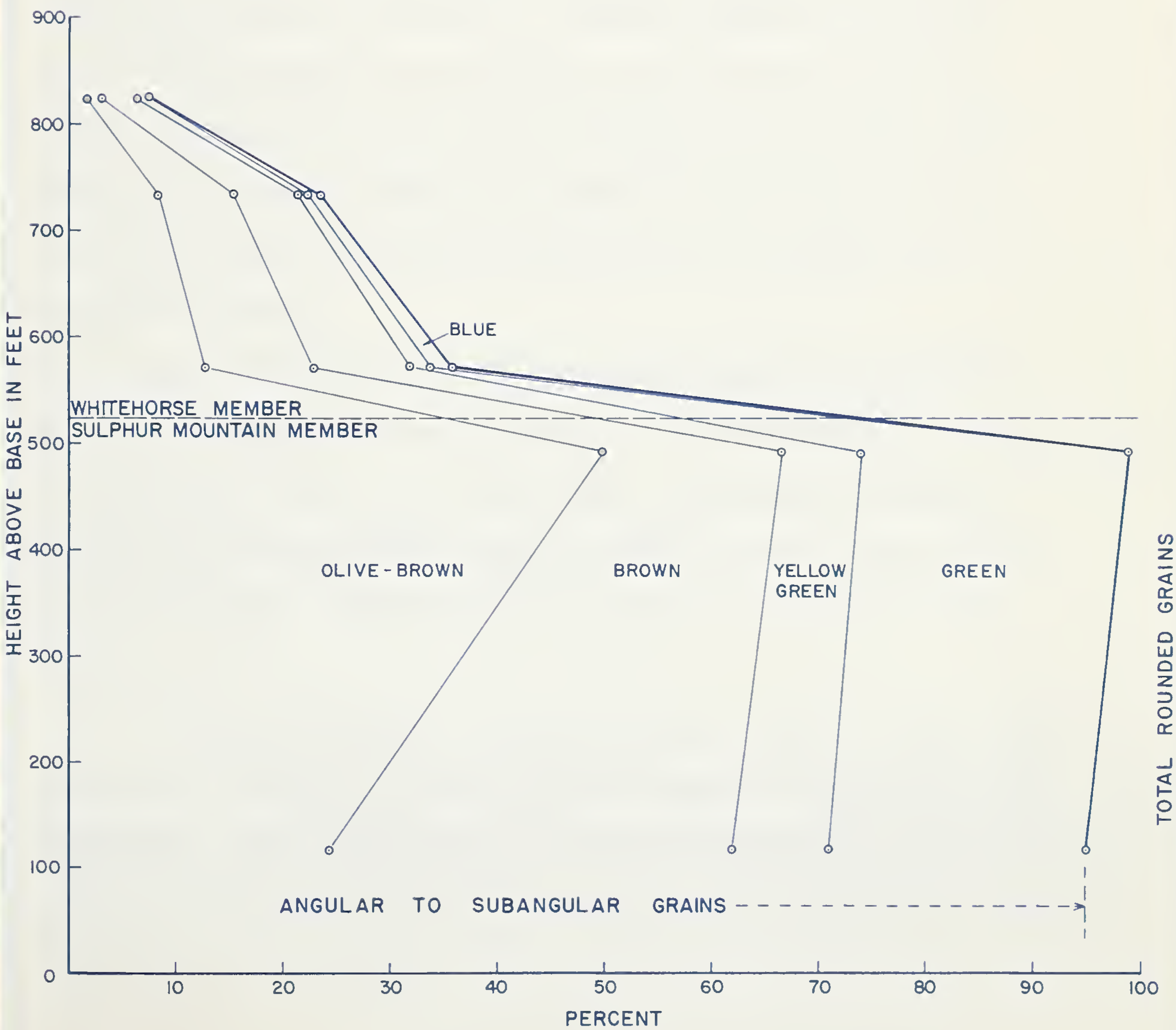


Fig. 3

cloudy darker tint to an intensity that rendered the crystals almost opaque.

(2) pale pink (5RP8/2) with an almost imperceptible tint of moderate blue (5B5/6).

(3) colourless and transparent.

Zircon grains were assigned to two broad groups with respect to angularity:

(a) angular and euhedral grains with pyramidal terminations. Some grains show finely developed zonary structure and also occasionally an extensive network of fissures. Irregular globular or accicular gas or liquid inclusions were present, the latter type being only occasionally parallel to the C-axis of the grain. All three colour varieties occur in this group. The grains are first cycle and those with pink to purple colour with micro-fissures are derived from a Pre-cambrian source;

(b) rounded, elliptical or roughly spherical grains. The surfaces of some grains were pitted and frosted to a moderate degree. Fissured and zoned grains also occur in this group. Inclusions of irregular globular or accicular, gas or liquid type are present. The accicular type inclusions are rarely oriented parallel to the C-axis of the grains.

Rounding of zircons is not a conclusive proof of their being multi-cycle in origin, as rounding can be caused by magmatic corrosion (Poldervaart, 1956). Rounding due to corrosion in magmatic chamber has, however, been observed to be more pronounced in the smaller grain sizes

(ibid, p. 531), and since the rounded grains of zircon in Spray River formation are more common in the coarser grain sizes, they are considered to have been rounded by several cycles of abrasion.

Figures 4 and 5 show the distribution of zircon grains on the basis of colour and angularity.

Other Heavy Minerals

Biotite:

A few grains of brown biotite were noted in all mounts examined, both in Banff and Cadomin areas, as angular flakes.

Chlorite:

This is present as a minor constituent as irregular green cleavage flakes in all samples but in relatively small amounts in the Cadomin section.

Hematite:

This is the most frequently occurring mineral in the heavy mineral residues examined from both the sections. It occurs as irregular aggregates.

Muscovite:

Muscovite mica was found in all samples examined. Most of the grains show some degree of abrasion.

Pyrite:

Pyrite is nearly as ubiquitous as is hematite. It occurs commonly as clusters and aggregates and rarely as octahedral or cubic crystals and as coatings on quartz grains. Occurrence of pyrite as coatings is indicative of at least some authigenic development.

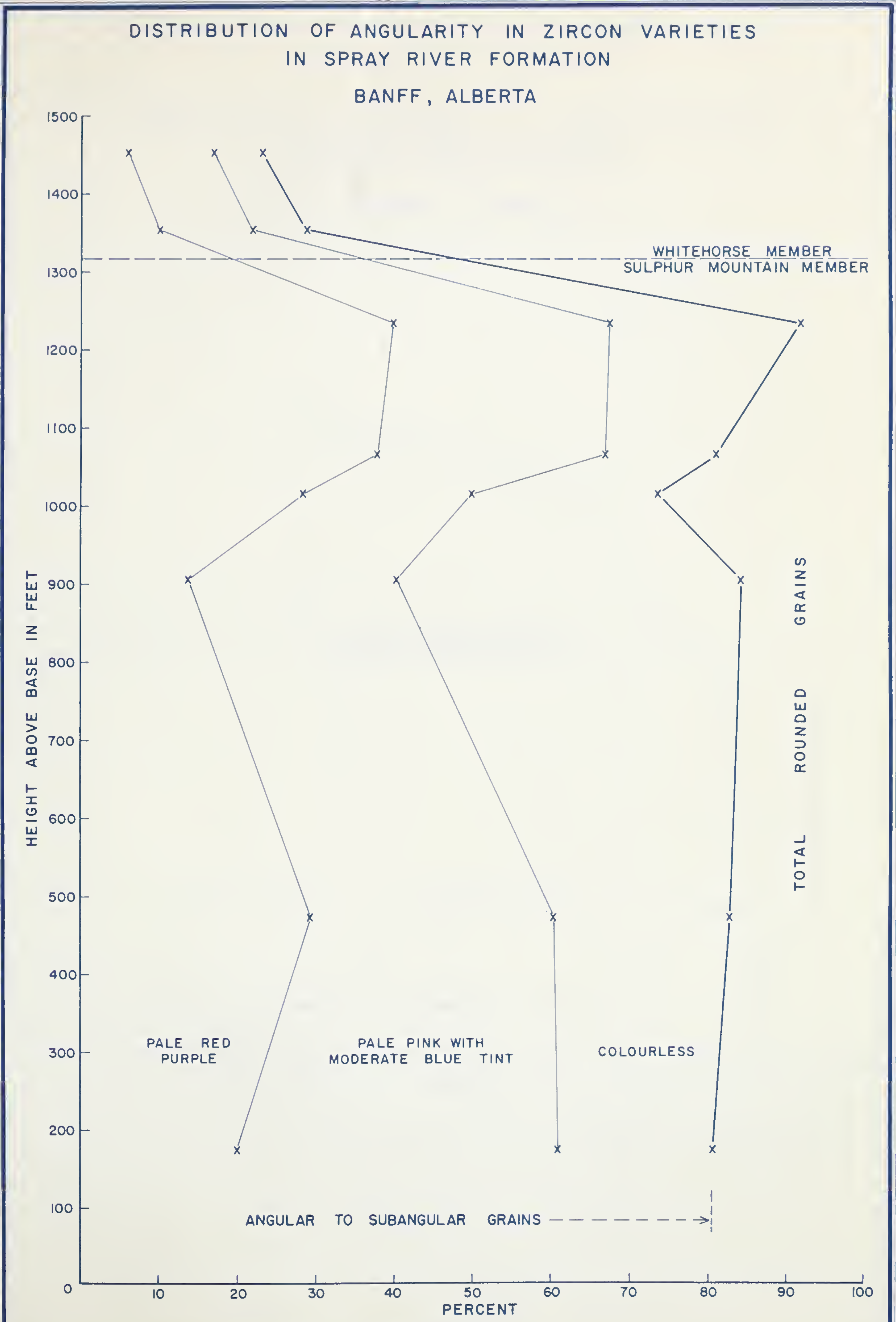
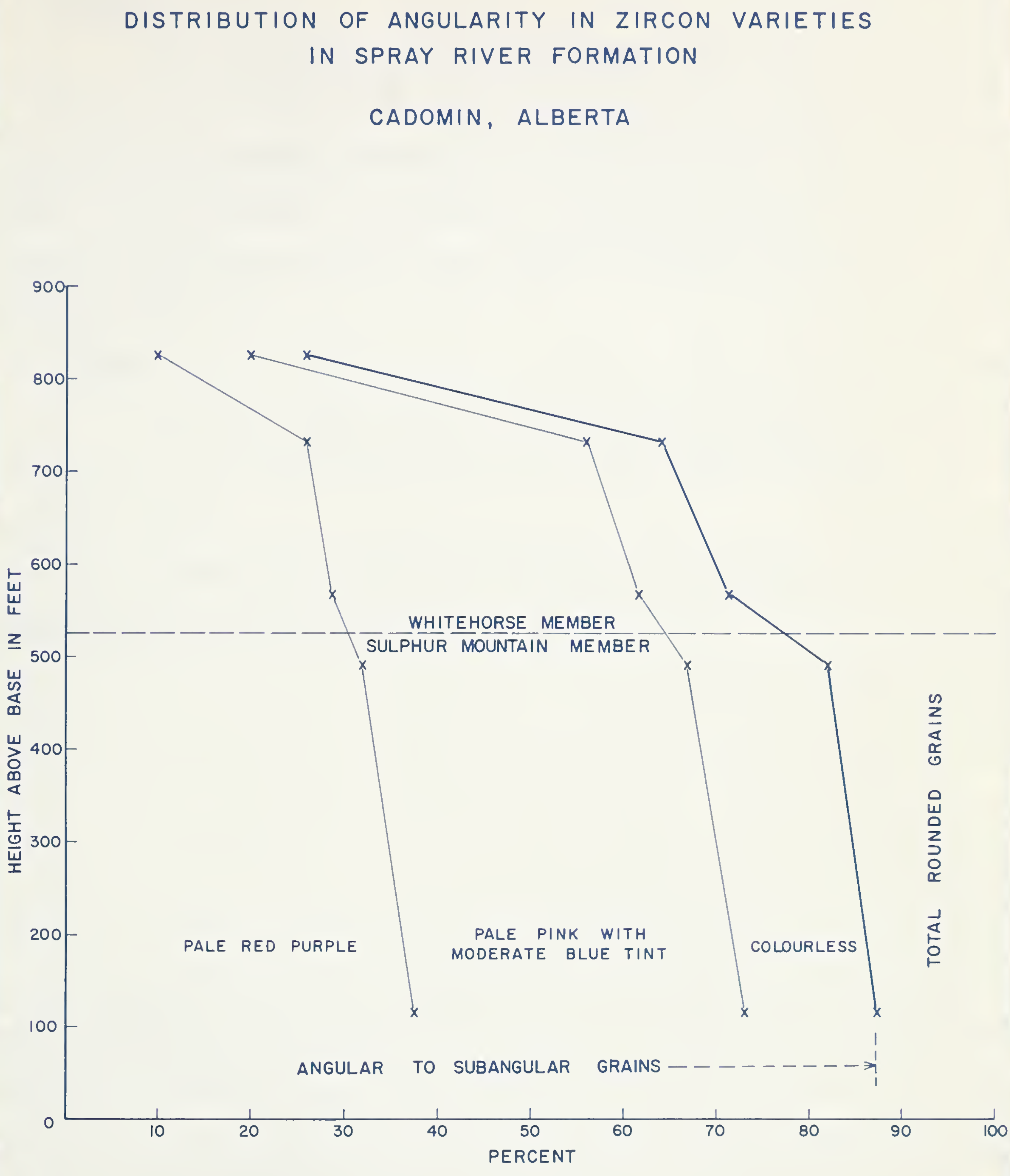

DISTRIBUTION OF ANGULARITY IN ZIRCON VARIETIES
IN SPRAY RIVER FORMATION
BANFF, ALBERTA
HEIGHT ABOVE BASE IN FEET
WHITEHORSE MEMBER
SULPHUR MOUNTAIN MEMBER
TOTAL ROUNDED GRAINS
PALE RED PURPLE
PALE PINK WITH MODERATE BLUE TINT
COLOURLESS
ANGULAR TO SUBANGULAR GRAINS
PERCENT
0
10
20
30
40
50
60
70
80
90
100
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500

Fig.4



DISTRIBUTION OF ANGULARITY IN ZIRCON VARIETIES
IN SPRAY RIVER FORMATION
CADOMIN, ALBERTA
HEIGHT ABOVE BASE IN FEET
900
800
700
600
500
400
300
200
100
0
WHITEHORSE MEMBER
SULPHUR MOUNTAIN MEMBER
PALE RED PURPLE
PALE PINK WITH
MODERATE BLUE TINT
COLOURLESS
TOTAL ROUNDED GRAINS
ANGULAR TO SUBANGULAR GRAINS
10
20
30
40
50
60
70
80
90
100
PERCENT

Fig. 5

Rutile:

Dusky red (5R3/4) rutile was identified in all samples. It occurs in both the sections. Many of the grains are angular to sub-angular and a few have sub-rounded to rounded terminations. In grains that had undergone less abrasion, longitudinal striations parallel to the prism edge are seen. Geniculated fragments were present, though rare.

Sphene:

Colourless, angular, euhedral grains of sphene making up less than 1% of the suite, were noted in two of the samples from the section at Banff.

Figures 6 and 7 show the distribution of dominant non-opaque minerals, viz. tourmaline, zircon and rutile.

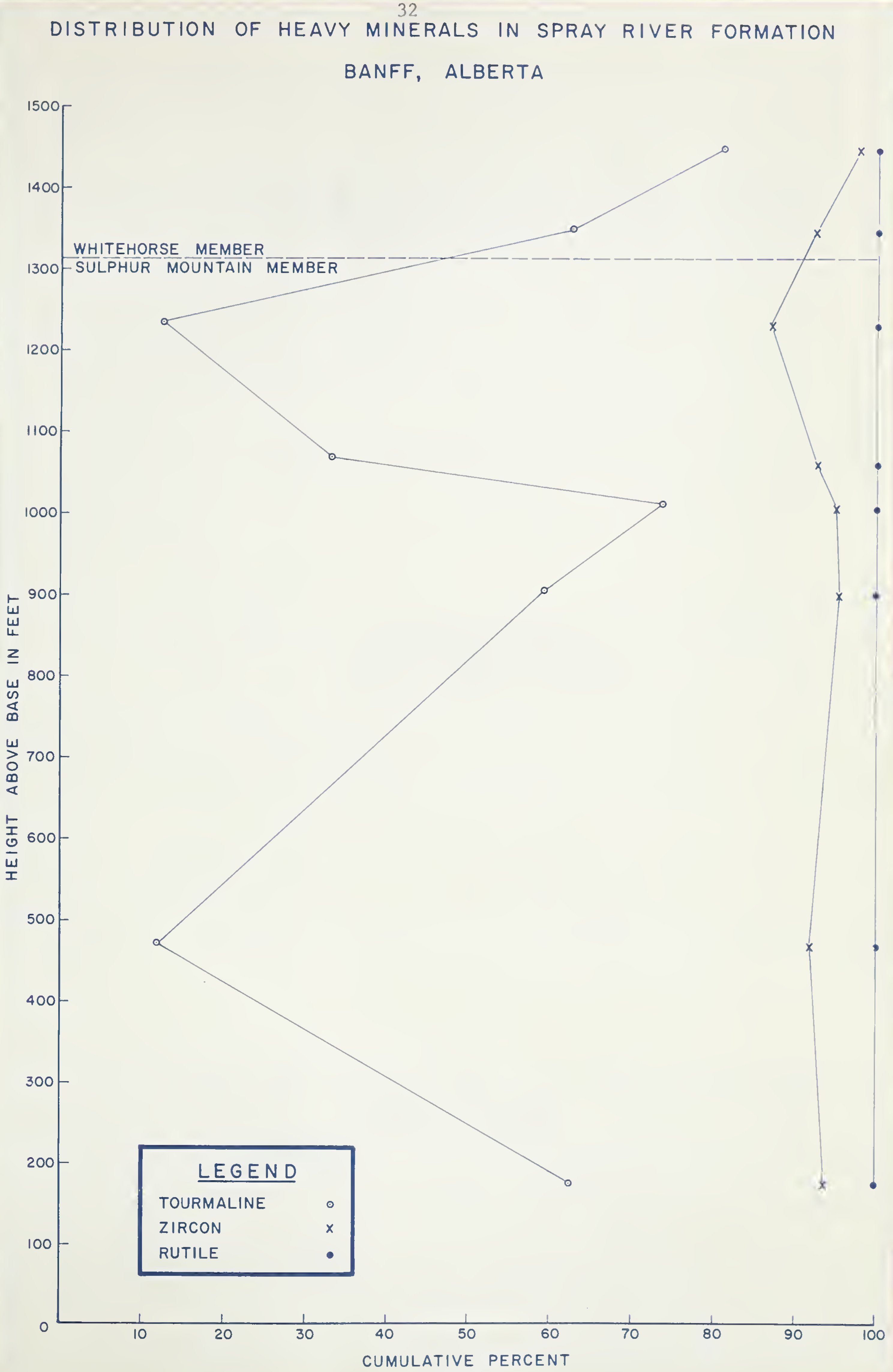

DISTRIBUTION OF HEAVY MINERALS IN SPRAY RIVER FORMATION
BANFF, ALBERTA
WHITEHORSE MEMBER
SULPHUR MOUNTAIN MEMBER
HEIGHT ABOVE BASE IN FEET
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
10
20
30
40
50
60
70
80
90
100
CUMULATIVE PERCENT
LEGEND
TOURMALINE
ZIRCON
RUTILE

Fig. 6

DISTRIBUTION OF HEAVY MINERALS IN SPRAY RIVER FORMATION

CADOMIN, ALBERTA

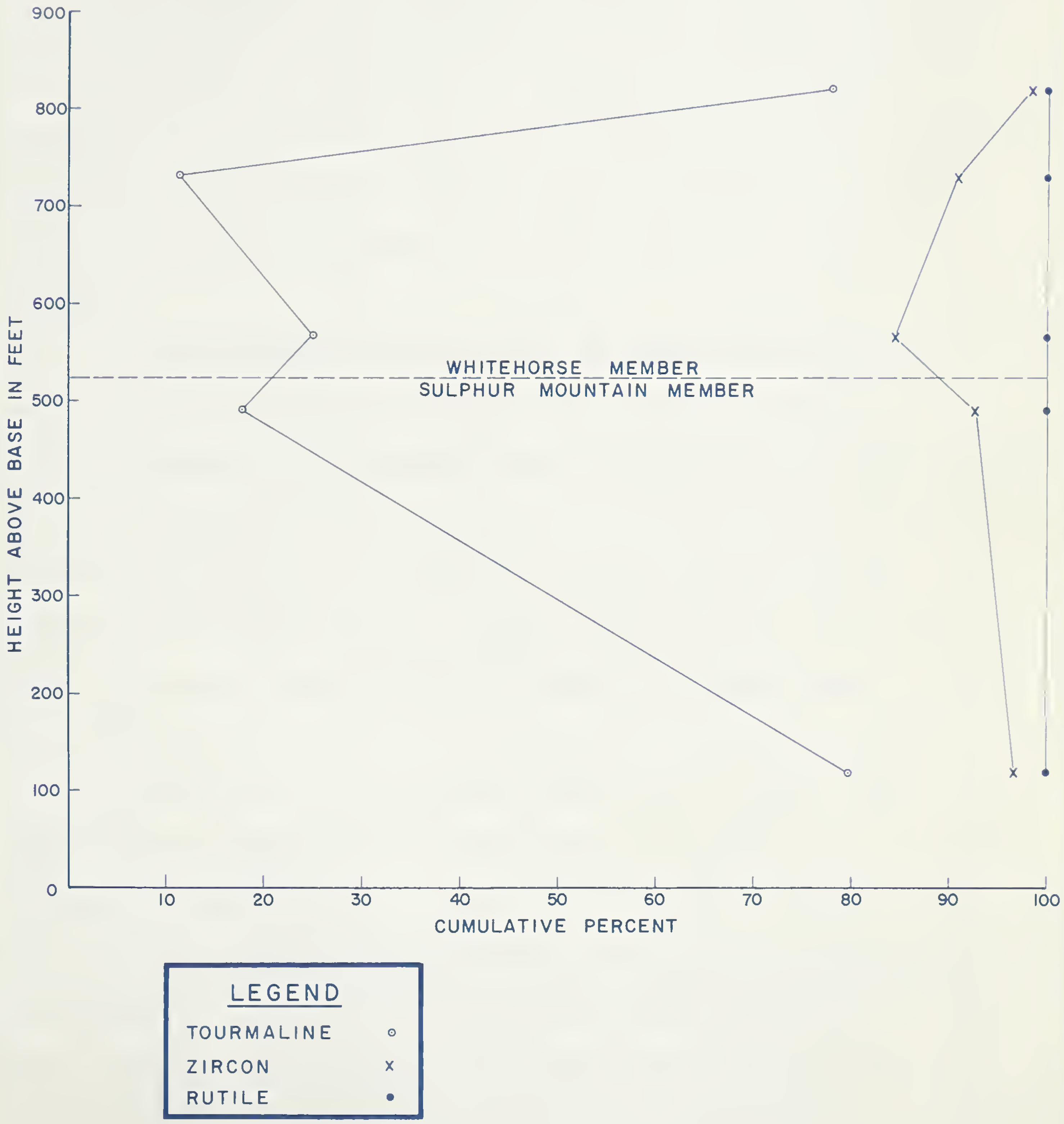


Fig. 7

C. Calcite-Dolomite Ratios

Specimens collected from the Spray River formation near Banff showed a considerable variation in degree of reaction when treated with 5% HCl. On the other hand, specimens from near Cadomin gave similar reactions with acid of the same concentration. This suggested a difference in calcite-dolomite ratios in the two sections.

In order to investigate this character of the formation, it was decided to determine the proportion of calcite and dolomite in the specimens as accurately as possible, using X-ray diffraction analysis. The procedure that was decided upon for this purpose is briefly as follows:

Ground samples of pure calcite and dolomite were mixed in several proportions and X-ray patterns run on each of them using copper radiation, a geiger-counter pick-up and Brown recorder. With a view to eliminating as many variables as possible, a standard procedure for preparation of the samples for X-ray was adopted, which is described in Appendix C (pp. 105-106 Appendix Section). The areas under the strongest peaks ($^{d}104$) for calcite and dolomite were calculated and the ratios used to plot a standard curve (fig. 8) for per cent dolomite of the total dolomite plus calcite content. This curve differs slightly from the calibration curve of Tennant and Berger (1957, p. 26).

Having set up a standard curve, the procedure described in the appendix was adopted for preparation of samples for X-raying eighty-two specimens collected from the Spray River formation near

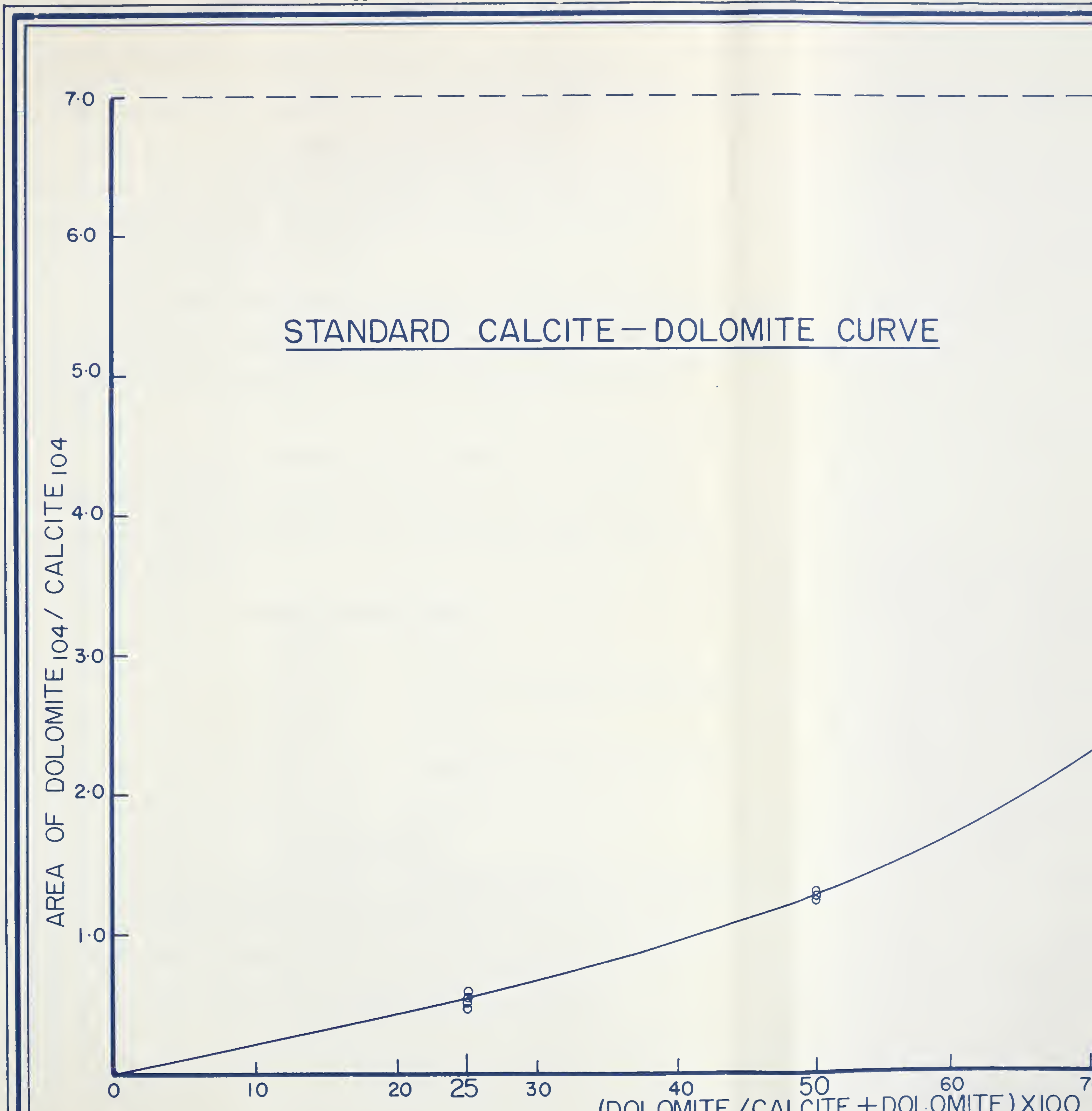
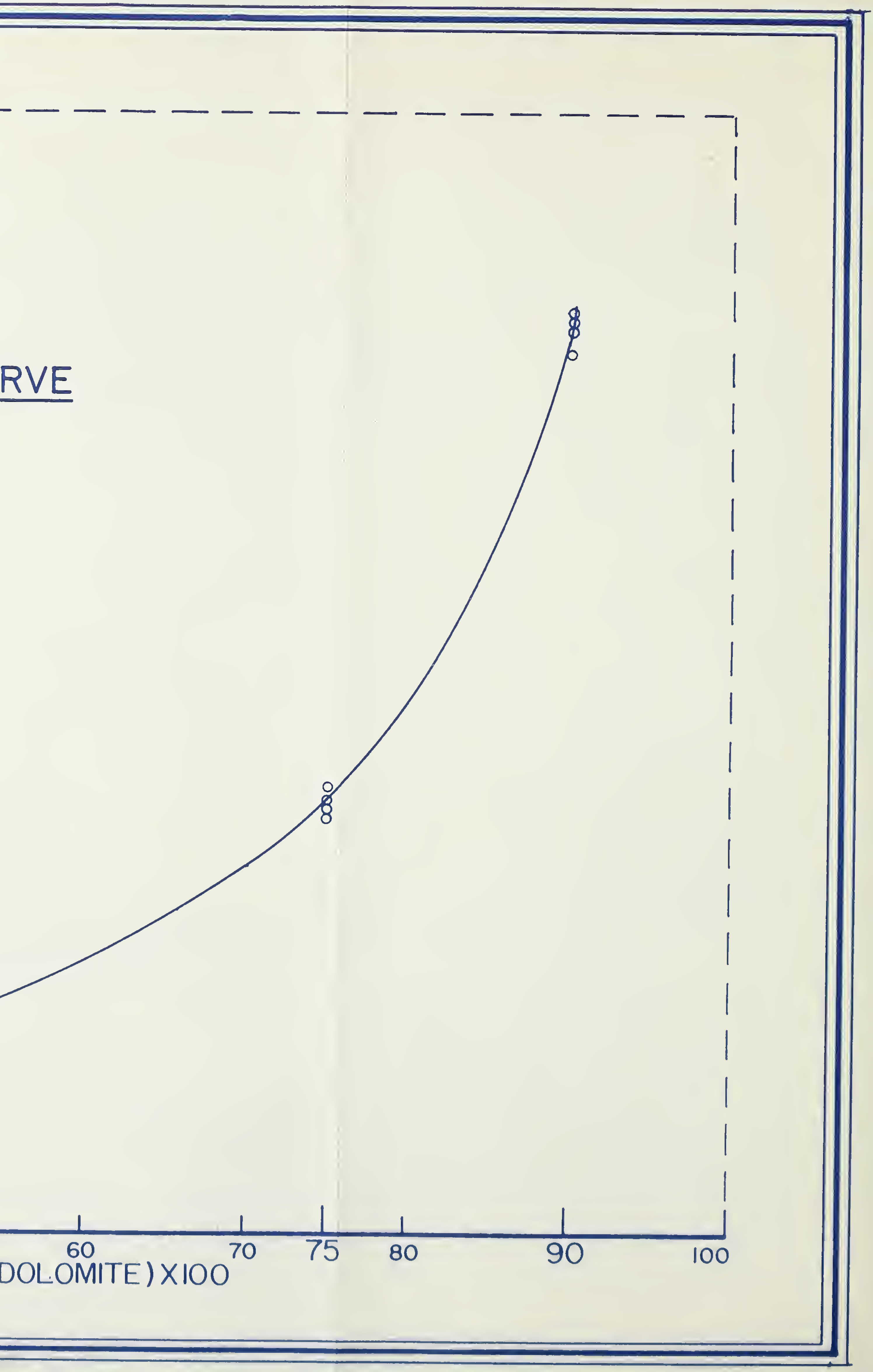

STANDARD CALCITE—DOLOMITE CURVE
AREA OF DOLOMITE 104 / CALCITE 104
7·0
6·0
5·0
4·0
3·0
2·0
1·0
0
10
20
25
30
40
50
60
(DOLOMITE / CALCITE + DOLOMITE) X100

FIGURE : 8



RVE
60
70
75
80
90
100
DOLOMITE) X100

Banff and Cadomin. Percentages of dolomite of total dolomite plus calcite content of the specimens were read from the standard curve. The calculations are shown in tables 4 and 5, pp. 110 to 114 of appendix. Graphs showing per cent dolomite plotted against stratigraphic height above the formation base are presented in figures 9 and 10.

In cases where the dolomite content was higher than 90%, it has been shown as 90%. This was necessitated because higher dolomite/calcite ratios could not be accurately read from the standard curve.

From figure 9 showing per cent dolomite vs. stratigraphic height above formation base for the Spray River section near Banff, the following general division of the section may be made on the basis of type of carbonate:

<u>Sulphur Mountain Member</u>	
00'-270'	Dolomitic
245'-550'	Interbedded calcitic and dolomitic
550'-907'	Covered
907'-1125'	Interbedded calcitic and dolomitic
1125'-1318'	Dolomitic
<u>Whitehorse Member</u>	
1318'-1537'	Interbedded calcitic and dolomitic

The calcitic and dolomitic designations in the above division have been made on the basis of 50% or more of the particular carbonate of the total dolomite plus calcite content of the rocks.

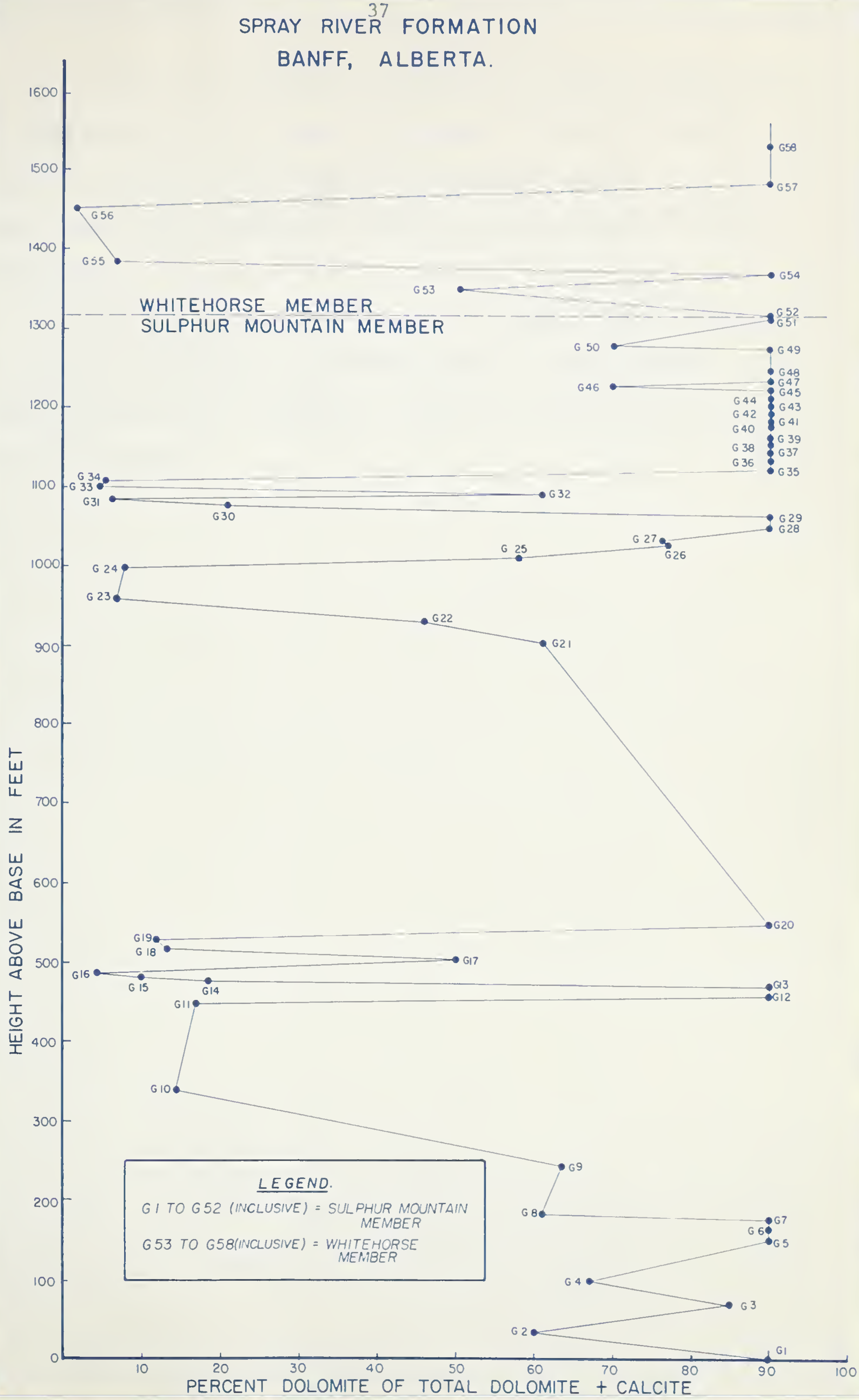

SPRAY RIVER FORMATION
BANFF, ALBERTA.
HEIGHT ABOVE BASE IN FEET
PERCENT DOLOMITE OF TOTAL DOLOMITE + CALCITE
WHITEHORSE MEMBER
SULPHUR MOUNTAIN MEMBER
LEGEND.
G 1 TO G 52 (INCLUSIVE) = SULPHUR MOUNTAIN MEMBER
G 53 TO G 58 (INCLUSIVE) = WHITEHORSE MEMBER

Fig 9

Thus the Sulphur Mountain member may be roughly divided into a lower dolomitic unit, a middle interbedded calcitic and dolomitic unit and an upper dolomitic unit. The Whitehorse member, on the other hand, may be considered a single interbedded calcitic and dolomitic unit.

The graph of per cent dolomite vs. height above base for the Spray River formation near Cadomin (fig. 10) shows that the entire formation here is dolomitic, marked by the total absence of a calcitic facies.

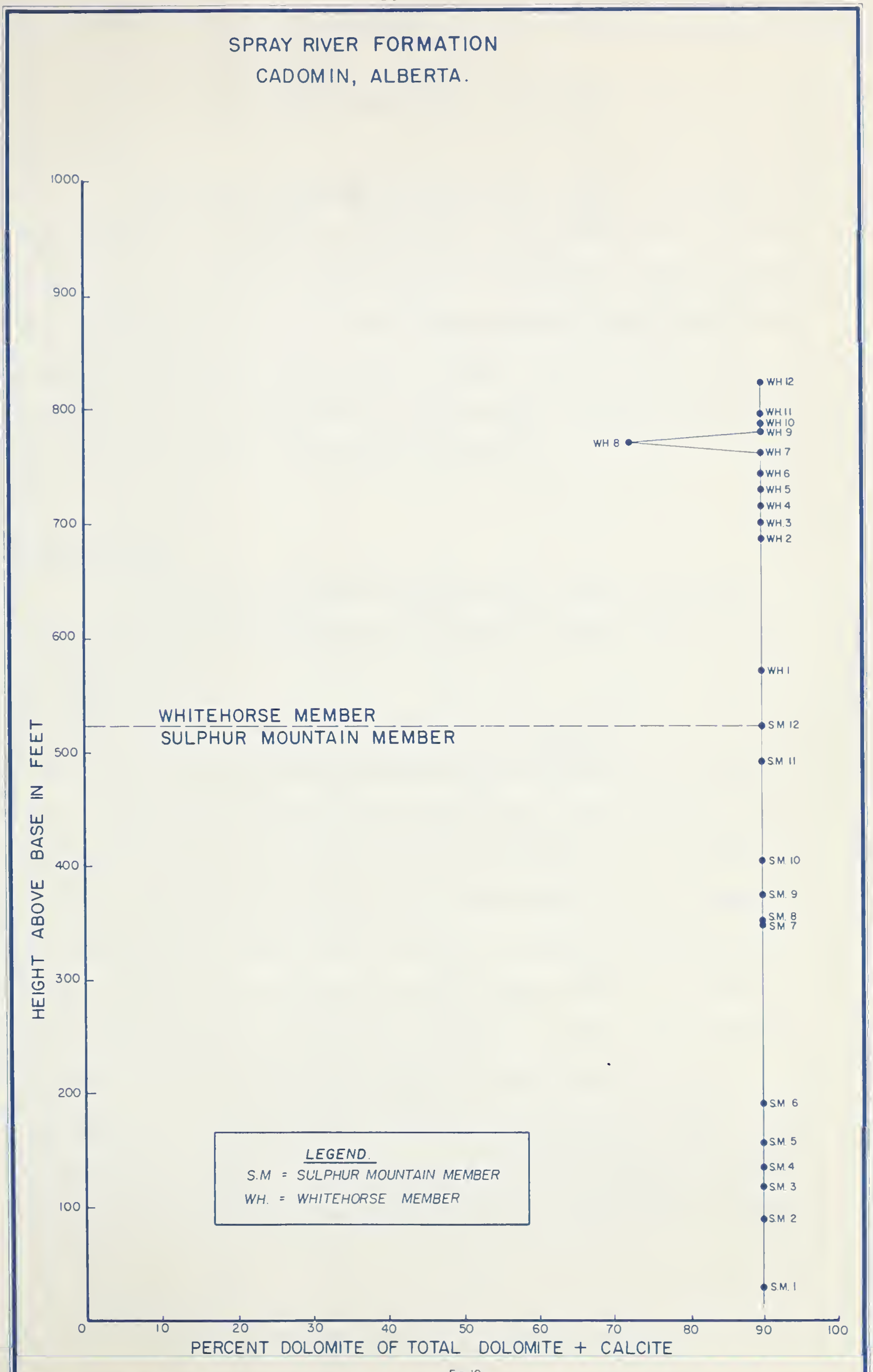

SPRAY RIVER FORMATION
CADOMIN, ALBERTA.
HEIGHT ABOVE BASE IN FEET
1000
900
800
700
600
500
400
300
200
100
0
10
20
30
40
50
60
70
80
90
100
PERCENT DOLOMITE OF TOTAL DOLOMITE + CALCITE
WHITEHORSE MEMBER
SULPHUR MOUNTAIN MEMBER
WH 12
WH 11
WH 10
WH 9
WH 8
WH 7
WH 6
WH 5
WH 4
WH 3
WH 2
WH 1
SM 12
SM 11
SM 10
SM 9
SM 8
SM 7
SM 6
SM 5
SM 4
SM 3
SM 2
SM 1
LEGEND.
S.M = SULPHUR MOUNTAIN MEMBER
WH. = WHITEHORSE MEMBER

Fig 10

D. Organic Matter and Iron Content

Five samples from the Sulphur Mountain member of the Spray River formation at Banff were selected for the determination of total iron and organic matter. Prior to the determination of organic matter, the acid-soluble content of the sieved fractions was removed by treatment with warm 10% HCl for at least 48 hours. Mr. A. Stelmach very kindly determined the per cent by weight content of organic matter and iron. The results are presented in table 3.

Organic Matter

The quantity of organic matter present varies considerably among different types of deposits. According to Trask (1955, p. 428) it depends upon:

"(1) the supply of organic matter in the overlying water;

(2) the rate of decomposition of the organic substances, while they are in the water or after they have accumulated in the sediments, and

(3) the movement of the water in which the materials are deposited."

It has been noted from data obtained from the north-western Gulf of Mexico that there exists an inverse relationship between the organic content of the sediments and the oxygen content of the overlying waters (Richards and Redfield, 1953-54, p. 279). Richly organic deposits (up to 25 or even 30 per cent of organic material) are characteristic of modern poorly-ventilated bodies (Kuenen, 1950, p. 13). To quote Trask (1955, p. 429) "few typically marine sediments contain more than 10% and equally few contain less than 0.5%" (organic matter).

Table Showing Organic and Iron Content of Sulphur Mountain Member, Banff

1 Sample No.	2 Colour	3 Stratigraphic position above base in feet	4 Loss on ignition weight % @ 100°C	5 Loss on ignition weight % 100°C-200°C	6 Loss on ignition (complete) weight % 200°C-1000°C	7 Combined water (H_2O)+	8 Organic material weight %	9 Ferric oxide (Fe_2O_3) weight %	10 Iron (Fe)
G47	Light Bluish Gray(5YR6/1)	1236	0.03	0.06	0.66	0.42	0.60	0.27	0.19
G24	Medium Bluish Gray (5B5/1)	999	0.05	0.03	0.90	0.49	0.80	0.64	0.45
G8	Grayish Black (N2)	185	0.51	0.12	4.82	2.45	4.20	2.72	1.90
G5	Grayish Black (N2)	152	3.65	1.68	11.24	6.22	5.90	3.76	2.63
G3	Dark Gray (N3)	70	0.85	0.61	5.26	3.53	3.80	3.20	2.24

Table 3

The quantity of organic matter in the Sulphur Mountain member near Banff varies from 0.6% to 5.9% by weight, which is within the limits indicated by Trask (1955, ibid) for typically marine sediments.

Iron Content

Iron is an ever-present constituent of sedimentary rocks and there are few sediments that are entirely free from it. It occurs in two valence form and passes readily from one to the other as a result of oxidation or reduction. Clarke (1916) calculated the average weight- per cent content of ferric iron in shales, sandstones and limestones as 4.03, 1.08 and 0.54 respectively.

The Sulphur Mountain member consists of siltstones and occasionally very fine sandstones. Clarke has not given the average weight- per cent of ferric iron content in siltstones. It may not be unreasonable to assume, however, that it lies somewhere between the shale value of 4.03% and the sandstone value of 1.08%.

The weight- per cent of total iron in the five samples analyzed are given in table 3. The average for these five samples (2.12) falls near the midpoint of Clark's values for shales and sandstones. The relation between organic content and ferric iron content is fairly constant and may be significant. The iron and organic matter decrease upwards in the Sulphur Mountain member. The tendency towards decrease in carbonaceous material in hand samples has been observed near 450 feet and 181 feet above the base in Banff and Cadomin sections respectively.

REGIONAL ANALYSIS OF DATA

1. Correlation

Information provided by the heavy mineral study suggests two possible correlations of the Banff and Cadomin sections. A rapid change in angularity takes place approximately at the Sulphur Mountain-Whitehorse contact in both sections. This is probably largely due to a slight change in grain size but may be time correlative. A slightly different correlation is suggested by the quantitative relationship between zircon and tourmaline. These two minerals make up most of the non-opaque heavy mineral suite but fluctuate widely in a complimentary fashion. Tourmaline increases rapidly at the expense of zircon near the base of the Whitehorse member in the Banff section, whereas the same type of change takes place about 250 feet above the base of the Whitehorse member at Cadomin. If the two sections are correlated on the tourmaline-zircon frequency, the base of the Whitehorse member is older at Cadomin than at Banff. Such a correlation would agree with the tentative and questioned position of this contact in Warren and Stelck's correlation chart. This fluctuation in the proportion of tourmaline vs. zircon may be a reflection of supply or may be a fine adjustment to sorting by size and specific gravity. If it is due to change in supply it is very likely to be time correlative at the two sections, if a result of sorting, time correlation is less certain.

2. Provenance

The composition of a sedimentary rock is dependant upon the terrigenous sources of supply of the sediments. The source minerals, however, are subject to disintegration and diagenetic changes, many do not survive combined destructive effects of these processes.

The heavy accessory mineral assemblages of the Spray River formation from both the Banff and Cadomin areas, are composed of stable minerals only. Tourmaline and zircon make up 90% of the non-opaques, while biotite, muscovite, rutile and sphene together constitute the remaining portion.

Krynine (1946) has classified tourmalines into five types on the bases of colour, inclusions and roundness, as indicators of provenance, as follows:

1. Granitic tourmaline: dark-brown, green or pink (with a greenish cast) full of inclusions.

2. Pegmatitic tourmaline: blue, with pleochrism in shades of mauve and lavender, inclusions rare.

3. Tourmaline from pegmatized injected metamorphic terrain: in pegmatized sandstones, brown pale to deep-brown, poor in inclusions, smaller than granitic tourmalines; in shales, phyllites and non-quartzose mica-schists, colourless to very brown, frequently full of black carbonaceous inclusions if the injected phyllite was originally a dark or black shale.

4. Sedimentary authigenic tourmaline: colourless small over-

growth on detrital grains, showing polar development at one end of the C-axis.

5. Reworked tourmaline from older sediments: from any of the above four primary sources that has been reworked.

The tourmalines of the Spray River formation of both areas belong to Krynine's first, second, fourth, fifth and possibly third types. These indicate contributions from acid igneous, metamorphic and sedimentary terrains.

Both first cycle and multi-cycle zircons are also present in the heavy accessory suites. The zircons of pale pink and pale red purple colour bear a similarity to those figured by Hutton (1950, plate 1, figs. 13, 16-19). Grains that show zoning are somewhat akin to ones figured by Bruce and Jewitt (1936, p. 12 text fig. 5, nos. 22 and 23) from some Canadian Precambrian granites. Some of the grains also exhibit a network of microfissures. Hutton (1950, p. 696) considers the development of these minute fractures the result of transformation of an original crystalline zircon into a partly or wholly amorphous state due to radiation from contained radioactive atoms. This transformation is accompanied by hydration and increase in volume with consequent decrease in density. The break-down and change of colour of zircons from colourless to hyacinth has been looked upon by Tomita (1954) as a measure of age. According to him, the hyacinth zircon has a Precambrian age, on the basis of time required to alter a colourless zircon to hyacinth type by radiation. Thus the presence of a considerable amount of first cycle hyacinth zircons in the Sulphur Mountain member represents a supply of sediments from a major igneous

Precambrian source. The Canadian Shield to the east is the only region of widespread exposures of such rocks. The fineness of the detrital grain size is suggestive of a low and/or distant source area. At the time of Sulphur Mountain deposition, the tectonic activity in the source area must have been very mild.

The Whitehorse member shows a tendency towards coarser grain-size with a marked increase in roundness in the detrital grains but an overall decrease in detrital material relative to authigenic carbonate, showing less terrigenous contribution. This member predominantly consists of dolomites, very fine-grained sandstones and calcitic or dolomitic orthoquartzites and protoquartzites. The orthoquartzites and protoquartzites include rounded to well-rounded chert and microquartzite and/or mudstone among the detrital constituents. Thus increase in roundness along with presence of the above detrital constituents and the change to carbonate, represents greater sedimentary contribution and a possible change of source.

McLearn's (1953) concept of the difference between eastern and western Triassic deposits, as referred to earlier, was verified by the writer, who failed to find any evidence of volcanic material in the Triassic samples studied.

Warren (oral communication) explains the existence of these two distinct facies of Triassic rocks by postulating the extension of the edge of the craton as far west as the western margin of the Rocky Mountains, forming a strong basement and eliminating the submarine volcanic activity present within the Eastern System. This, however, does not entirely explain the lack of ash-falls in Alberta unless the prevailing

wind direction was such that ash produced by explosive activity in British Columbia would not be carried eastward. Using the mean Triassic pole-position (based on North American measurements) of latitude 57° north and longitude 92° east (Du Bois, 1958), the position of a point midway between Banff and Cadomin, Alberta, would have been at 25° north latitude and 106° west longitude. A position of 25° north latitude falls within the present Trade Wind belt, and according to Laming (1958, p. 182) "the dominant directions of the Trade Winds in the northern and southern hemispheres are northeast and southeast respectively". Hence, western Alberta in Triassic time had perhaps dominantly northeasterly winds, and this might account for the absence of ash-falls in the Triassic of the area under study. It is noteworthy, however, that Permo-Triassic time was one of anomalous wind direction because of the influence of mountainous topography according to Laming (1958).

3. Depositional Environment

The deposits of the Spray River formation of the study areas were laid down in a shallow marine trough at the site of the present Rocky Mountains and foothills of Western Canada.

The water was not so shallow as to allow wave-action to obliterate the distinct laminations present in Sulphur Mountain member. The member was deposited in a relatively unagitated sea below prevailing wave-base. The preservation of organic matter and development of authigenic pyrite as coatings on quartz grains suggest that at least the lower part of the Sulphur Mountain member was deposited in an environment of somewhat limited circulation. Bottom waters were probably somewhat reducing and devoid of bottom-dwelling scavengers. The upper part of this member perhaps records a transition to a more normally oxygenated open-sea environment conducive to rapid oxidation of organic matter.

The Whitehorse member probably represents deposition above wave-base. Repeated washing and winnowing action of the waves of the shallow sea together possibly with a slightly coarse supply of sediments from the source has given rise to well-sorted mature rock types in the orthoquartzites and protoquartzites of this member. Presence of authigenic tourmaline, which has been considered to be indicative of marine environment of deposition (Krynine, 1946) in this member, suggests slightly different water chemistry during it deposition.

Chilingar and Bissell (1957) have attempted to correlate seven different outcrop carbonate sections separated by distances from

six miles to 175 miles in Nevada and Utah, U.S.A., on the basis of Ca/Mg ratios determined by chemical analyses. The conclusions they have arrived at are summarised below:

(i) Higher magnesium content is indicative of shallower and warmer waters.

(ii) Increase in Ca/Mg ratio is due to gradual subsidence and deepening of the depositional basin.

(iii) Ca/Mg ratio can be successfully used over short distances as a supporting tool rather than as an index by itself.

(iv) Variations over short distances in Ca/Mg ratio is a function of deepening and shallowing of the sea-bottom, rather than of climatic changes, as the latter were likely to affect the various areas not too far apart, more or less equally.

The outcrops of Spray River formation in the Banff and Cadomin areas are about 145 miles apart. The dolomite-calcite facies changes in the two sections are of two different types: the Spray River formation near Banff shows a fluctuating dolomite/calcite ratio, whereas the formation near Cadomin has a consistently high dolomite/calcite ratio. On the basis of Chilingar's and Bissell's findings it would be concluded that the fluctuations of dolomite/calcite ratios in the Banff section are indicative of oscillation in the depth of water. In the Cadomin area, on the other hand, the water-depth was more constant and on the average somewhat shallower and warmer.

4. Summary

1. Two possible correlations of the Spray River formation near Banff and Cadomin are suggested, based upon:

    (a) change in angularity in heavy minerals,

    (b) quantitative relationship between tourmaline and zircon.

If the two sections are correlated on the basis of tourmaline-zircon frequency, the base of Whitehorse member is older at Cadomin than at Banff. This is in conformity with the tentative and questioned position of this contact in Warren and Stelck's (1954) correlation.

2. Heavy mineral suites of both the sections consist of only stable minerals viz., tourmaline, zircon and rutile. Angular tourmaline and zircon grains represent contribution from an igneous source. Presence of angular hyacinth zircons denotes the igneous source as being the Canadian Shield to the east.

3. The Whitehorse member has a greater contribution from a sedimentary terrain, which indicates a possible change of source area.

4. The formation was deposited in a shallow marine trough. The depth of water oscillated in the Banff area, whereas in the Cadomin area the water-depth was more constant and on the average somewhat shallower and warmer.

5. The lower part of Sulphur Mountain member was deposited in a relatively unagitated sea, below prevailing wave-base and in an environment of somewhat limited circulation. Bottom waters were

probably somewhat reducing and devoid of bottom-dwelling scavengers. The upper part of this member shows transition to a more normally oxygenated open-sea environment.

6. The Whitehorse member was probably deposited above wave-base, and the presence of authigenic tourmaline suggests a slightly different water chemistry during deposition of this member.

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APPENDIX A

Stratigraphic Sections

Spray River Formation, Banff Area, Alberta

Location: Confluence of Spray and Goat Rivers
Sec. 5, Tp. 25, R. 11 W. 5th Meridian
Overlying formation .... Fernie (Jurassic)

Distance above base in feet	Thickness in feet	
		WHITEHORSE MEMBER
1526-1537	11	DOLOMITE - dark yellowish orange (10YR6/6) weathering, light bluish gray (5B7/1), thick-bedded (2'-2.5'), slabby to blocky, vuggy porosity with abundant 1/4" to 1/2" vugs.
1498-1526	28	COVERED
1487-1498	11	DOLOMITE - medium gray (N5) weathering, medium bluish gray (5B5/1), thin-bedded (2"-12"), flaggy to slabby, scattered pin-point vugs.
1452-1487	35	COVERED
1429-1452	23	SANDSTONE - moderate yellow (5Y7/6) weathering, grayish yellow (5Y8/4), medium-grained, thick-bedded (2'-2.5'), slabby to blocky, calcareous.
1385-1429	44	COVERED
1371-1385	14	SANDSTONE - light brown (5YR5/6) weathering, light olive gray (5Y6/1) fine-grained, thin-bedded (2"-10"), flaggy to slabby, chalky, friable, calcareous.
1351-1371	20	SANDSTONE - light brown (5YR6/4) weathering, light olive gray (5Y6/1), very fine-grained, thin-bedded (2"-10"), flaggy to slabby, rather hard, dense, dolomitic.

Distance above base in feet	Thickness in feet	
1318-1351	33	LIMESTONE - light brownish gray (5YR6/1) weathering, light gray (N7), thin-bedded (4"-6"), flaggy to slabby, fossiliferous.
	219	TOTAL WHITEHORSE MEMBER
		SULPHUR MOUNTAIN MEMBER
1313-1318	5	SILTSTONE - light brownish gray weathering, (5YR6/1) medium light gray (N6), thin-bedded (4"-6"), partly cross-laminated, flaggy to platey, dolomitic, interbedded with SHALE (80:20), medium dark gray (N4), laminated (1/10"-1/5") platey to papery, fissile.
1297-1313	16	SILTSTONE - light brown (5YR6/2) weathering, light brownish gray (5YR6/1), thin-bedded (2"-4"), flaggy to slabby, compact, micaeous, dolomitic.
1282-1297	15	COVERED
1277-1282	5	SILTSTONE - light brown (5YR6/4) weathering, medium bluish gray (5B5/1), thin-bedded (2"-4"), flaggy to slabby, hard, dense, pyritic, dolomitic.
1270-1277	7	SILTSTONE - brownish gray (5YR4/1) weathering, light brownish gray (5YR6/1), thin-bedded (4"-6"), flaggy to slabby, dolomitic.
1250-1270	20	COVERED
1236-1250	14	SILTSTONE - light brownish gray (5YR6/1) weathering, medium light gray (N6), thin-bedded (2"-6"), flaggy to slabby, hard, dense, micaceous, dolomitic.
1231-1236	5	SILTSTONE - brownish gray (5YR6/1) nodular weathering, light brownish gray (5YR6/1), thin-bedded (2"-4"), flaggy to slabby, compact, micaceous, pyritic, dolomitic.

Distance above base in feet	Thickness in feet	
1226-1231	5	SILTSTONE - medium light gray (N6), well-defined thin beds (2"-4"), cross-laminated (cross-laminations due to partings of carbonaceous material and/or pyrite), slabby to platey, micaceous, dolomitic.
1214-1226	12	SILTSTONE - light gray (N6) weathering, medium bluish gray (5B5/1), thin-bedded (2"-6"), very vaguely laminated, flaggy to slabby, rather compact, dolomitic.
1204-1214	10	SILTSTONE - light brownish gray (5YR6/1) weathering, medium light gray (N6), well-defined thin beds (2"-4"), finely cross-laminated (laminations due to partings of carbonaceous material and/or pyrite), slabby to platey, friable, dolomitic, micaceous, argillaceous.
1196-1204	8	SILTSTONE - light olive gray (5Y6/1) weathering, light gray (N7), thin-bedded (4"-6"), flaggy to slabby, dense, argillaceous dolomitic.
1185-1196	11	SILTSTONE - light olive gray (5YR6/1) weathering, medium light gray (N6), well-defined thin beds (2"-6") vaguely laminated, flaggy to slabby, dolomitic micaceous, hard, when struck with hammer gives phonolitic ring and breaks with conchoidal fracture.
1180-1185	5	SILTSTONE - light brownish gray (5YR6/1) weathering, medium bluish gray (5B5/1), thin-bedded (2"-6"), flaggy to slabby, hard, compact, dolomitic.
1176-1180	4	SILTSTONE - brownish gray (5YR6/1) weathering, medium bluish gray (5B5/1), well-defined thin beds (2"-6"), slabby to flaggy, vaguely laminated, hard, dense, dolomitic, slightly argillaceous.
1166-1176	10	COVERED

Distance above base in feet	Thickness in feet	
1157-1166	9	SILTSTONE - light olive gray (5Y6/1) weathering, medium light gray (N6), thin-bedded (2"-6"), flaggy to slabby, dolomitic interbedded with SHALE (60:40), medium dark gray (N4), laminated (1/10"-1/5") papery to platey, fissile.
1146-1157	11	SILTSTONE - brownish gray (5YR4/1) weathering, medium bluish gray (5B5/1), thin-bedded (4"-6"), flaggy to slabby, dolomitic, dense, hard, gives a phonolithic ring when hit with hammer, breaks with conchoidal fracture.
1136-1146	10	SILTSTONE - light brownish gray (5YR6/1) weathering, medium bluish gray (5B5/1) to light gray (N7), well-defined thin beds (2"-1'), finely cross-laminated (laminations due to parting of organic material and/or pyrite), platey to slabby, rather hard, dense, dolomitic.
1125-1136	11	SILTSTONE - light brownish gray (5YR6/1) weathering, medium light gray (N6), thin-bedded (2"-6") with vague laminations, laminations being due to organic material and/or pyrite, flaggy to platey, compact, slightly micaceous, dolomitic.
1114-1125	11	SILTSTONE - light brownish gray (5YR6/1) weathering, medium bluish gray (5B5/1), well-defined very thin beds (1"-1 1/2"), flaggy to platey, vaguely evenly laminated, rather hard, dense, dolomitic.
1109-1114	5	COVERED
1101-1109	8	SILTSTONE - light brownish gray (5YR6/1) weathering, medium bluish gray (5B5/1), thin-bedded (4"-6"), flaggy to slabby, dense, calcareous.
1094-1101	7	SILTSTONE - light olive brown (5Y6/1) weathering, medium light gray (N6), thin-bedded (4"-6") vaguely laminated (laminations due to partings of carbonaceous material and/or pyrite), flaggy to slabby, rather dense, calcareous, interbedded with SHALE (40:60), medium dark gray (N4), laminated (1/10"-1/5") papery to platey, rather compact.

Distance above base in feet	Thickness in feet	
1086-1094	8	SILTSTONE - light olive gray (5Y6/1) weathering, medium gray (N5), well-defined very thin beds (6"-1'), evenly laminated (fine laminations due to partings of carbonaceous material and/or pyrite), flaggy to slabby, hard, dense, micaceous, calcareous.
1078-1086	8	SILTSTONE - light brownish gray (5YR6/1) weathering, medium bluish gray (5B5/1) to medium dark gray (N4), well-defined thin beds (4"-6") cross-laminated (laminations due to partings of carbonaceous material and/or pyrite), flaggy to slabby, argillaceous.
1066-1078	12	SHALE - dark gray (N4) laminated (1/10"-1/5"), papery to platey, slightly calcareous, rather compact.
1051-1066	15	SILTSTONE - light brownish gray (5YR6/1) weathering, medium bluish gray (5B5/1), thin-bedded (6"-1'), flaggy to slabby, hard, dense, dolomitic.
1036-1051	15	SILTSTONE - light brownish gray (5YR6/1) weathering, medium light gray (N6), thin-bedded (6"-1') flaggy to slabby, dense, hard, dolomitic, interbedded with SHALE (80:20) medium gray (N5) laminated (1/10"-1/5") papery to platey, calcareous.
1030-1036	6	SILTSTONE - light brownish gray (5YR6/1) weathering, medium gray (N6), well-defined thin beds (6"-10") finely cross-laminated (laminations due to partings of carbonaceous material and/or pyrite), flaggy to slabby, argillaceous, micaceous, dolomitic.
1015-1030	15	SILTSTONE - light brownish gray (5YR6/1) weathering, medium bluish gray (5B5/1), well-defined, thin beds (5"-1') finely cross-laminated (laminations due to partings of calcareous material and/or pyrite) flaggy to slabby rather compact, dense, dolomitic.

Distance above base in feet	Thickness in feet	
999-1015	16	SILTSTONE - light brownish gray (5YR6/1) weathering, medium bluish gray (5B5/1) well-defined thin beds (4"-6"), vaguely laminated (laminations owing to partings of carbonaceous material and/or pyrite) flaggy to slabby, calcareous.
974-999	25	SILTSTONE - light olive gray (5Y6/1) weathering, medium bluish gray (5B5/1), well-defined thin beds (4"-6"), finely cross-laminated (laminations being due to carbonaceous material and/or pyrite), flaggy to slabby, rather hard, dense, calcareous.
960-974	14	COVERED
932-960	28	SILTSTONE - light olive gray (5Y6/1) weathering, medium bluish gray (5B5/1), well-defined thin beds (3"-6"), vaguely laminated (laminations due to partings of carbonaceous material and/or pyrite), flaggy to slabby, calcareous, interbedded with SHALE (70:30), medium dark gray (N4), laminated (1/10"-1/5") papery to platey, slightly calcareous.
907-932	25	SILTSTONE - light olive gray (5Y6/1) weathering, medium bluish gray (5B5/1), well-defined thin beds (6"-1') finely laminated (laminations being due to partings of carbonaceous material and/or pyrite), flaggy to slabby, hard, calcareous, dense, interbedded with SHALE (60:40), medium dark gray (N5), laminated (1/5"-1/2"), papery to platey, rather compact, calcareous.
892-907	15	SILTSTONE - light olive gray (5Y6/1) nodular weathering, medium bluish gray (5B5/1), well-defined thin beds (2"-6"), vaguely cross-laminated (laminations due to partings of carbonaceous material and/or pyrite), flaggy to slabby, dolomitic, interbedded with SHALE (80:20), brownish gray (5YR4/1), laminated (1/5"-1/10"), platey to papery, fissile, calcareous.

Distance above base in feet	Thickness in feet	
550-892	342	COVERED
542-550	8	SILTSTONE - light brownish gray (5YR6/1) weathering, medium bluish gray (5B5/1) well-defined thin beds (3"-6"), flaggy to slabby, dolomitic, interbedded with SHALE (60:40), brownish gray (5YR4/1), laminated (1/10"-1/5"), papery to platey, fissile.
530-542	12	COVERED
519-530	11	SILTSTONE - light brownish gray (5YR6/1) weathering, medium bluish gray (5B5/1), well-defined thin beds (2"-6"), cross-laminated (laminations being due to partings of organic material and/or pyrite), slabby to flaggy, calcareous, argillaceous, interbedded with SHALE (80:20) dark gray (N3), laminated (1/10"-1/5"), papery to platey, calcareous.
506-519	13	SILTSTONE - light olive gray (5Y6/1) weathering, medium bluish gray (5B5/1), thin bedded (6"-1'), slabby to flaggy, hard, dense, calcareous.
488-506	18	SILTSTONE - light olive gray (5Y6/1) weathering, dark gray (N3), thin-bedded (2"-6"), vaguely laminated (laminations due to partings of carbonaceous material and/or pyrite), flaggy to slabby, slightly argillaceous, interbedded with SHALE (50:50), brownish gray (5YR4/1), laminated (1/10"-1/4"), slabby to flaggy, rather compact, calcareous.
473-488	15	SILTSTONE - light olive gray (5YR6/1) weathering, medium light gray (N6) to medium gray (N5), well-defined thin beds (2"-1'), finely cross-laminated (laminations due to partings of organic material and/or pyrite), platey to slabby, rather hard, dense, calcareous, micaceous, interbedded with SHALE (60:40), brownish gray (5YR4/1), laminated (1/10"-1/5"), papery to platey, fissile.

Distance above base in feet	Thickness in feet	
460-473	13	SILTSTONE - light brownish gray (5YR6/1) weathering, medium dark gray (N4), thin-bedded (2"-1'), flaggy to slabby, hard, dense, dolomitic, gives phonolitic ring when struck with hammer, conchoidal fracture.
450-460	10	SILTSTONE - light brownish gray (5YR6/1) weathering, medium dark gray (N4), thin-bedded (2"-4"), rather hard, dense, interbedded with SHALE (60:40), brownish gray (5YR4/1), laminated (1/10"-1/5"), papery to platey, fissile, calcareous.
245-450	205	SILTSTONE - brownish gray (5YR6/1) weathering, dark gray (N3), thin-bedded (1'-1.5'), slabby, hard, breaks with phonolitic ring when hit with hammer, conchoidal fracture, interbedded with SHALE (70:30), medium gray (N5), very thin-bedded (1"-2"), flaggy, calcareous.
185-245	60	SILTSTONE - light brownish gray (5YR6/1) weathering, greyish black (N2), thin-bedded (1.5'-2'), slabby, hard, dolomitic, interbedded with SHALE (50:50), medium gray (N5), very thin-bedded (1"-2"), flaggy, rather compact, fissile.
177-185	8	SILTSTONE - grayish black (N2), well-defined thin beds (1'-1.5'), finely laminated (laminations due to partings of carbonaceous material and/or pyrite), slabby, hard, fossiliferous, *Claraia stachi* (Bittner) bearing zone.
165-177	12	SILTSTONE - light brown (5YR6/1) weathering, dark gray (N3) in well-defined thin beds (1'-1.5'), finely laminated (laminations being due to partings of carbonaceous material and/or pyrite), slabby, dense.
152-165	13	SILTSTONE - dark gray (N3) to grayish black (N2) in well-defined thin beds (1'-1.5'), finely laminated (laminations being due to partings of carbonaceous material and/or pyrite), slabby, compact, dolomitic, interbedded with SHALE (50:50) dark gray (N2), thinly laminated (1/10") papery, fissile.

Distance above base in feet	Thickness in feet	
2.5-152	149.5	SILTSTONE - grayish black (N2) thick-bedded (1.5'-2.5'), with vague laminations, slabby to blocky, hard, dense, gives phonolitic ring when hit with hammer, conchoidal fracture, carbonaceous, micaceous, interbedded with SHALE (60:40) light brownish gray (5YR6/1), laminated (1/10"-1/4"), papery to platey, fissile, very soft, dolomitic.
0.0-2.5	2.5	TRANSITION LIMESTONE (reworked) - light brownish gray (5YR6/1) weathering, medium bluish gray (5B5/1), thin-bedded (1'-1.5'), slabby, hard, conchoidal fracture.
	1318	TOTAL SULPHUR MOUNTAIN MEMBER
	1537	TOTAL SPRAY RIVER FORMATION
		Underlying Formation - Rocky Mountain Quartzite

Note (1): In SILTSTONES, referred to above, the ratio of carbonate content to silicate content, in general, is more or less equal. Some are silty dolomites and silty limestones, but because of similarity in appearance the field term of "SILTSTONE" has been applied to all of them.

Note (2): Code numbers e.g. (5YR6/1) etc., refer to the Rock-Color Chart (1951).

Spray River Formation, Cadomin Area, Alberta

Location: Confluence of McLeod and Whitehorse rivers, along railroad cut
Sec. 24, Tp. 46, R. 24 W. 5th Meridian
Overlying formation .... Fernie (Jurassic)

Distance above base in feet	Thickness in feet	
		WHITEHORSE MEMBER
794-824	30	SANDSTONE - light brown (5YR6/4) weathering, light gray (N7), fine-grained, thin-bedded (4"-10"), flaggy to slabby, hard, dense, dolomitic.
788-794	6	DOLOMITE - yellow (5Y7/6) weathering, light bluish gray (5B7/1), thin-bedded (4"-10"), flaggy to slabby, hard, compact.
764-788	24	DOLOMITE - very light gray (N8) weathering, medium bluish gray (5B5/1), thin-bedded (2"-10"), flaggy to slabby, dense, calcite fracture filled.
744-764	20	SANDSTONE - yellowish gray (5Y8/1) weathering, very light gray (N8), fine-grained, thin-bedded (2"-4"), flaggy to slabby, dolomitic.
732-744	12	SANDSTONE - yellowish gray (5Y8/1) weathering, very light gray (N8), fine to medium-grained, thin-bedded (2"-6"), flaggy to slabby, compact, chalky, dolomitic.
702-732	30	SILTSTONE - light brownish gray (5YR6/1) weathering, pale purple (5P6/2), well-defined thin beds (4"-10"), with flaggy to slabby wavy carbonaceous flecks, compact, micaceous, vuggy porosity, dolomitic.
672-702	30	SILTSTONE - light brownish gray (5G8/1) weathering, pale red purple (5RP6/2), thick-bedded (1'-2'), slabby to blocky, very hard, gives phonolitic ring when struck with hammer, conchoidal fracture.

Distance above base in feet	Thickness in feet	
569-672	103	COVERED
544-569	25	SILTSTONE - very light gray (N8) weathering, light bluish gray (5G8/1), thin-bedded (4"-10"), flaggy to slabby, compact, pin-point vugs, dolomitic.
524-544	20	COVERED
	300	TOTAL WHITEHORSE MEMBER
		SULPHUR MOUNTAIN MEMBER
492-524	32	SILTSTONE - light olive gray (5Y6/1) weathering, light bluish gray (5B7/1), thin-bedded (2"-6"), flaggy to slabby.
467-492	25	SILTSTONE - light brown (5YR6/1) weathering, pale red purple (5Y6/1), thick-bedded (6"-1.5'), slabby to blocky, hard, dense, gives phonolitic ring when struck with hammer, conchoidal fracture, small scattered vugs.
405-467	62	COVERED
375-405	30	SILTSTONE - brownish gray (5YR4/1) nodular weathering, light gray (N7), thick-bedded (6"-2'), slabby to blocky, hard, dense, dolomitic.
350-375	25	SILTSTONE - light brownish gray (5YR6/1) weathering, medium bluish gray (5B5/1), thick-bedded (4"-1.5'), slabby to blocky, rather hard, micaceous, dolomitic.
349-350	1	SHALE - light brownish gray (YR6/1), laminated (1/10"-1/5"), platey to papery, fissile, dolomitic.
314-349	35	SILTSTONE - dusky yellow (5Y6/4) weathering, very light gray (N8), thin-bedded (4"-6"), flaggy to slabby, fossiliferous, calcareous, rather friable, vuggy porosity.

Distance above base in feet	Thickness in feet	
181-314	133	COVERED
155-181	26	SILTSTONE - light olive gray (5Y6/1) weathering, medium bluish gray (5B5/1), thick-bedded (6"-1.5'), slabby to blocky, hard, dense, dolomitic.
134-155	21	SILTSTONE - light olive gray (5Y6/1) weathering, medium bluish gray (5B5/1) in well-defined thin beds (2"-6"), cross-laminated (cross-laminations due to partings of carbonaceous material and/or pyrite), platey to flaggy, argillaceous, dolomitic.
119-134	15	SILTSTONE - light olive gray (5Y6/1) weathering, medium bluish gray (5B5/1) in well-defined thin beds (2"-6"), cross-laminated (cross-lamination due to partings of carbonaceous material and/or pyrite), platey to flaggy, argillaceous, dolomitic.
89-119	30	SILTSTONE - medium gray (N5), thin-bedded (2"-4"), flaggy to slabby, slightly argillaceous, dolomitic.
53-89	36	SILTSTONE - light olive gray (5Y6/1) weathering, medium bluish gray (5B7/1), well-defined thin beds (4"-6"), wavy laminated (laminations due to partings of carbonaceous material and/or pyrite), flaggy to slabby, micaceous, dolomitic.
30-53	23	COVERED
0.00-30	30	SILTSTONE - light brownish gray (5YR6/1) weathering, light bluish gray (5B7/1) to medium bluish gray (5B5/1), well-defined thin beds (2"-4"), cross-laminated (laminations due to partings of carbonaceous material and/or pyrite), flaggy to slabby, micaceous, dolomitic.

524	TOTAL SULPHUR MOUNTAIN MEMBER
824	TOTAL SPRAY RIVER FORMATION

Underlying Formation - Mississippian Rundle Limestone.

Note (1): In general, the ratio of carbonate content to silicate content in the SILTSTONES is more or less equal. Some are silty dolomites and silty limestones, but because of similarity in appearance the field designation of "SILTSTONE" has been applied to all of them.

Note (2): Code numbers, e.g. (5YR6/1) etc., refer to the Rock-Color Chart (1951).

APPENDIX B

Description of Thin-Sections

Spray River Formation, Sulphur Mountain Member
(Banff Area)

Thin section number - 3960 Hand specimen No. G1

Location - Base of formation 0.00' (contact of Rocky Mountain Quartzite and Spray River formation)

Description:

Colour - (a) fresh surface - medium bluish gray (5B5/1).
(b) weathered surface - light brownish gray (5YR6/1).

Structure - vague indication of bedding.

Texture - clastic, very fine sand to coarse silt (average 0.05 mm.), very angular to angular, very fine sand and very angular coarse silt, poorly-sorted, well-cemented, loosely packed, no porosity.

Composition:

Main components:

25% Quartz - very fine sand to coarse silt, average size 0.05 mm., very angular to angular fine sand, very angular coarse silt, contacts very rare, grains separated by carbonate cement, rare irregular dusty inclusions present, straight extinction.

10% Carbonaceous material

Varietal Minerals ($>$ 1%):

5% Hematite

3% Muscovite

1% Pyrite

Accessory minerals ($\leqslant$1%):

Zircon, tourmaline, feldspar (plagioclase)

Interstitial matrix (clay-size):

5% Clay minerals

Cement:

50% Carbonate, more than 90% dolomite (by X-ray)

Classification: Carbonaceous silty dolomite.

Thin section number - 3961 Hand specimen No. G6

Location - About 165.0 feet above base

Description:

Color - (a) fresh surface - dark gray (N3)

(b) weathered surface - light brownish gray (5YR6/1)

Structure - very vague indications of bedding

Texture - clastic, very fine sand to coarse silt (average 0.10 mm.), angular to sub-angular very fine sand and very angular coarse silt, very ill-sorted, moderately packed, well-cemented, no porosity.

Composition:

Main components:

45% Quartz - angular to sub-angular, average size 0.05 mm., straight extinction, rare contacts, grains separated by carbonate cement, inclusions uncommon and very minute.

10% Carbonaceous material

Varietal minerals ($>$1%):

1% Pyrite

1% Hematite

Accessory minerals ($\leqslant$1%):

Muscovite, feldspar, zircon, tourmaline

Interstitial matrix (clay size):

5% Clay minerals

Cement:

37% Carbonate - more than 90% dolomite (by X-ray)

Pore space - nil

Classification: Carbonaceous dolomitic siltstone.

Thin section number - 3962 Hand specimen No. G10

Location - 340 feet above base

Description:

Color - (a) fresh surface - medium bluish gray (5B5/1)

(b) weathered surface - light brownish gray (5YR6/1)

Structure - none apparent

Texture - clastic, very fine sand to coarse silt (average 0.05 mm.), sub-angular to sub-rounded, very fine sand and very angular coarse silt, very ill-sorted, loosely packed, well-cemented, no porosity.

Composition:

Main components:

25% Quartz - sub-angular to sub-rounded very fine sand, coarse silt, some up to 0.07 mm., average size 0.05 mm. straight extinction, a few show irregular minute dusty inclusions, grains separated by carbonate, very rare contacts.

10% Carbonaceous material

Varietal material (>1%):

1% Pyrite

1% Hematite

Accessory minerals ($\leq 1\%$):

Zircon, muscovite, tourmaline

Interstitial matrix (clay-size):

5% Clay minerals

Cement:

57% Carbonates, 85.5% calcite, 14.5% dolomite (by X-ray)

Pore space - nil

Classification: Carbonaceous dolomitic silty limestone

Thin section number - 3963 Hand specimen No. G15

Location - About 483 feet above base

Description:

Color - (a) fresh surface - medium light gray (N6)

(b) weathered surface - light olive gray (5YR6/1)

Structure - very well-defined fine cross-laminations.

Texture - clastic, very fine sand to coarse silt (average 0.05 mm.), sub-angular to sub-rounded very fine sand and very angular coarse silt, ill-sorted, loosely packed, no porosity.

Composition:

Main components:

45% Quartz - sub-angular to sub-rounded very fine sand to coarse silt, average size 0.05 mm., straight extinction, a few grains with minute inclusions, very rare contacts, grains separated by carbonate cement.

10% Carbonaceous material

Varietal minerals (>1%):

6% Hematite

1% Muscovite

1% Pyrite

Accessory minerals (≤1%):

Tourmaline, zircon, rutile, plagioclase feldspar

Interstitial matrix (clay-size):

3% Clay minerals

Cement:

33% Carbonate - 90% calcite, 10% dolomite (by X-ray)

Pore space - nil

Classification: Carbonaceous dolomitic calcitic siltstone

Thin section number - 3964 Hand specimen No. G18

Location - 519 feet above base

Description:

Color - (a) fresh surface - medium bluish gray (5B5/1)

(b) weathered surface - light brownish gray (5YR6/1)

Structure - well-defined fine laminations

Texture - clastic, very fine sand to medium silt (average 0.05 mm.), very angular to angular fine sand and very angular medium silt, loosely packed, poorly sorted, well-cemented, no porosity.

Composition:

Main components:

25% Quartz - very angular to angular, average size 0.05 mm., contacts very rare, grains separated by carbonate, rare irregular globules as inclusions, straight extinction.

Varietal minerals (>1%):

7% Carbonaceous material

Accessory minerals (<1%):

Pyrite

Muscovite

Tourmaline

Zircon

Interstitial matrix (clay-size):

2% Clay minerals

Cement:

65% Carbonates, 86.5% calcite, 13.5% dolomite (by X-ray)

Pore space - nil

Classification: Dolomitic silty limestone

Thin section number - 3965 Hand specimen No. G22

Location - About 932 feet above base

Description:

Colour - (a) fresh surface - medium bluish gray (5B5/1)

(b) weathered surface - light olive gray (5Y6/1)

Structure - very fine well-defined laminations

Texture - clastic, very fine sand to medium silt (average 0.05 mm.), very angular to angular very fine sand, very angular medium silt, poorly sorted, well-cemented, loose packing, no porosity.

Composition:

Main components:

45% Quartz - very angular to angular grains, average size 0.05 mm., rare contacts, grains separated by carbonate content,

irregular globular inclusions, very rare strained grains ($< 5\%$), commonly straight extinction.

10% Carbonaceous material

Varietal minerals ($>1\%$):

1% Pyrite

1% Muscovite

Accessory minerals ($\leqslant 1\%$):

Pyrite, zircon, tourmaline, rutile

Interstitial matrix (clay size):

2% Clay minerals

Cement:

40% Carbonate, 56% calcite, 44% dolomite (by X-ray)

Pore space - nil

Classification: Carbonaceous dolomitic calcitic siltstone.

Thin section number - 3966 Hand specimen No. G24

Location - 999 feet above base

Description:

colour - (a) fresh surface - light bluish gray (5B7/1)

(b) weathered surface - light olive gray (5Y6/1)

Structure - well-defined very fine cross-laminations, due to carbonaceous material and/or pyrite.

Texture - clastic, very fine sand to coarse silt (average 0.07 mm.), angular very fine sand and very angular coarse silt, poorly sorted, well-cemented, loosely packed, no porosity.

Composition:

Main components:

35% Quartz - very fine sand to coarse silt (average 0.77 mm.), angular very fine sand and very angular coarse silt, contacts rare, grains separated by carbonate content, dusty inclusions but rare, straight extinction.

Varietal minerals (>1%):

8% Carbonaceous material

5% Hematite

1% Muscovite

Accessory minerals (≤1%):

Pyrite, zircon, tourmaline

Interstitial matrix (clay-size):

3% Clay minerals

Cement:

47% Carbonate - 92% calcite, 8% dolomite (by X-ray)

Pore space - nil

Classification: Arenaceous dolomitic limestone.

Thin section number - 3967 Hand specimen No. G26

Location - 1030 feet above base

Description:

Colour - (a) fresh surface - medium bluish gray (5B5/1)

(b) weathered surface - light brownish gray (5YR6/1)

Structure - vaguely laminated

Texture - clastic, very fine sand to medium silt, average size being 0.05 mm., very angular to angular fine sand and very angular medium silt, poorly sorted, well-cemented, moderate to loosely packed, no porosity.

Composition:

Main composition:

45% Quartz - angular, average size 0.05 mm., occasionally one contact between the grains, otherwise carbonate content separates the grains, straight extinction, rare strained grains about 5%, rare irregular globular inclusions.

Varietal minerals (>1%):

8% Carbonaceous material

1% Muscovite

Accessory minerals (≤1%):

Pyrite, zircon, tourmaline, rutile

Interstitial matrix (clay size):

5% Clay minerals

Cement:

40% Carbonate, 77% dolomite, 23% calcite

Pore space - nil

Classification: Calcitic dolomitic siltstone.

Thin section number - 3968 Hand specimen No. G28

Location - 1051 feet above base

Description:

Colour - (a) fresh surface - medium bluish gray (5B5/1)

(b) weathered surface - light brownish gray (5YR6/1)

Structure - none apparent

Texture - clastic, very fine sand to medium silt (average size 0.05 mm.), angular fine sand and very angular medium silt, poorly sorted, well-cemented, moderate to loosely packed, no porosity.

Composition:

Main components:

42% Quartz - angular, average size 0.05 mm., contacts rare but occasionally one contact present, straight extinction, rarely strained grains less than 5%.

Varietal minerals (>1%):

8% Carbonaceous material

3% Muscovite

2% Hematite

1% Pyrite

Accessory Minerals ($\leqslant$1%):

Tourmaline, zircon, feldspar (plagioclase)

Interstial matrix (clay-size):

5% Clay minerals

Cement:

38% Carbonate - 90% dolomite (by X-ray)

Pore space - nil

Classification: Dolomitic siltstone.

Thin section number - 3969 Hand specimen No. G34

Location - about 1109 feet above base

Description:

Colour - (a) fresh surface - light bluish gray (5B7/1)

(b) weathered surface - light gray (N7)

Structure - none apparent

Texture - clastic, very fine sand to medium silt (average size 0.05 mm.), very angular to angular very fine sand and very angular medium silt, very ill-sorted, well-cemented, moderate to loosely packed, no porosity.

Composition:

Essential components:

10% Quartz - very fine to medium silt, average grain size being 0.05 mm., very angular to angular, contacts rare, grains being separated by carbonate content, however, occasionally one contact may be present, rare irregular globular inclusions, straight extinction, about 5% strained grains.

Varietal minerals ($>$1%):

5% Hematite

5% Carbonaceous material

Accessory minerals ($\leqslant$1%):

Tourmaline, zircon, muscovite, plagioclase feldspar

Interstial matrix (clay-size):

5% Clay minerals

Cement:

75% Carbonate - 94.5% calcite, 5.5% dolomite

Pore space - nil

Classification: Stylolitic silty limestone.

Special feature: stylolitic development - teeth-like projections of one side fit into sockets of like dimensions on the other side.

Thin section number - 3970 Hand specimen No. G37

Location - 1146 feet above base

Description:

Colour - (a) fresh surface - medium bluish gray (5B5/1)

(b) weathered surface - light brownish gray (5YR6/1)

Structure - well-defined fine cross-lamination due to carbonaceous material and/or pyrite.

Texture - clastic, very fine sand to medium silt (average 0.05 mm.), very angular to angular fine sand and very angular medium silt, ill-sorted, well-cemented, moderately packed, no porosity.

Composition:

Main components:

45% Quartz - very fine sand to medium silt, average size being 0.05 mm., very angular to angular, one contact, occasionally two, but more often the grains are separated by carbonates, very rare irregular globular inclusions, straight extinction, about 5% strained grains however.

Varietal minerals (>1%):

6% Carbonaceous material

5% Hematite

1% Muscovite

1% Feldspar plagioclase

Accessory minerals ($\leqslant$1%):

Pyrite, tourmaline, zircon, rutile

Interstitial matrix (clay-size):

4% Clay minerals

Cement:

37% Carbonate - more than 90% dolomite (by X-ray)

Pore space - nil

Classification: Dolomitic siltstone.

Thin section number - 3971 Hand specimen No. G41

Location - 1185 feet above base

Description:

Colour - (a) fresh surface - medium bluish gray (5B5/1)

(b) weathered surface - light brownish gray (5YR6/1)

Structure - none apparent

Texture - clastic, very fine sand to medium silt (average 0.05 mm.), angular very fine sand and very medium silt, poorly-sorted, well-cemented, loosely packed, no porosity.

Composition:

Main components:

40% Quartz - very fine sand to medium silt, average size being 0.05 mm., contacts rare, occasionally one, grains being separated by carbonates, straight extinctions, strained grains about 10%, rare globular irregular inclusions.

Varietal minerals ($>1\%$):

10% Hematite

5% Carbonaceous material

1% Pyrite

Accessory minerals ($\leqslant 1\%$):

Zircon, tourmaline, plagioclase feldspar

Interstitial matrix (clay-size):

5% Clay minerals

Cement:

38% Carbonate - 86.5% folomite, 13.5% calcite (by X-ray)

Pore space - nil

Classification: Hematitic calcitic dolomitic siltstone.

Thin section number - 3972 Hand specimen No. G43

Location - 1204 feet above base

Description:

Colour - (a) fresh surface - light gray (N7)

(b) weathered surface - light olive gray (5Y6/1)

Structure - none apparent

Texture - clastic, very fine sand to coarse silt, average .065 mm., very angular to angular very fine sand very angular coarse silt, poorly sorted, well-indurated, well-cemented, moderate to loose packing, no porosity.

Composition:

Main components:

50% Quartz - very fine sand to coarse silt, average size being .065 mm., very angular to angular, contacts more often rare, grains being separated by dolomite, occasionally one contact and very rare two contacts.

Varietal minerals ($>$ 1%):

6% Hematite

1% Pyrite

Accessory minerals ($\leq$ 1%):

Muscovite, tourmaline, zircon, rutile, plagioclase feldspar

Interstitial matrix (clay-size):

7% Clay minerals

Cement:

35% Carbonate - more than 90% dolomite (by X-ray)

Pore space - nil

Classification: Dolomitic sandstone (very fine sand).

Thin section number - 3973 Hand specimen No. G45

Location - 1226 feet above base

Description:

Colour - (a) fresh surface - light bluish gray (5B7/1)

(b) weathered surface - light brownish gray (5YR6/1)

Structure - none apparent

Texture - clastic, very fine sand to medium silt, average 0.05 mm., very angular to angular very fine sand and very angular medium silt, ill-sorted, well-cemented, moderate to loose packed, no porosity.

Composition:

Main components:

45% Quartz - very fine sand to medium silt, average size being 0.06 mm., some grains go up to 0.11 mm., angular to sub-angular, contacts rare, grains being separated by dolomite content, very rarely one or two contacts however, very rarely irregular minute dusty inclusions, straight extinction common, very rare strained grains less than 3%.

Varietal minerals (>1%):

8% Carbonaceous material

6% Hematite

1% Pyrite

Accessory minerals ($\leqslant$1%):

Muscovite, tourmaline, zircon, rutile, plagioclase feldspar

Interstitial matrix (clay-size):

4% Clay minerals

Cement:

35% Carbonate - more than 90% dolomite (by X-ray)

Pore space - nil

Classification: Dolomitic sandstone (very fine sand)

Thin section number - 3974 Hand specimen No. G47

Location - 1236 feet above base

Description:

Colour - (a) fresh surface - light brownish gray (5YR6/1)

(b) weathered surface - brownish gray (5YR4/1)

Structure - none apparent

Texture - clastic, very fine sand to coarse silt (average 0.07 mm.), very angular to angular fine sand and very angular coarse silt, very ill-sorted, well-cemented, moderate to loosely packed, no porosity.

Composition:

Main components:

45% Quartz - very fine sand to coarse silt, average size being 0.07 mm., some grains go up to 0.12 mm., very angular to angular, contacts commonly rare, grains being separated by carbonate content, occasionally one contact and very rarely two contacts, minute very rare inclusions, straight extinction, strained grains very rare, less than 2%

Varietal minerals (>1%):

6% Hematite

6% Carbonaceous material

1% Muscovite - slender and lath-shaped

Accessory minerals (≤1%):

Pyrite, tourmaline, zircon, rutile, plagioclase feldspar

Interstitial matrix (clay-size):

4% Clay minerals

Cement:

37% Carbonate - more than 90% dolomite (by X-ray)

Pore space - nil

Classification: Dolomitic sandstone (very fine sand).

Thin section number - 3975 Hand specimen No. G49

Location - 1277 feet above base

Description:

Colour - (a) fresh surface - light brownish gray (5YR6/1)

(b) weathered surface - brownish gray (5YR4/1)

Structure - none apparent

Texture - clastic, very fine sand to coarse silt (average 0.07 mm.), angular to sub-angular very fine sand and very angular coarse silt, very ill-sorted, well-cemented, moderate to tightly packed, no porosity.

Composition:

Main components:

50% Quartz - very fine sand to coarse silt, average size being 0.07 mm., rarely grains maybe up to 0.12 mm., angular

to sub-angular, one to two contacts, grains sometimes separated by carbonate content, very small irregular dusty inclusions present but rare, straight extinction, strained grains rare, in the order of 3%.

Varietal minerals ($>$1%):

5% Carbonaceous material

3% Hematite

Accessory minerals ($\leqslant$1%):

Muscovite, pyrite, tourmaline, zircon, rutile, plagioclase feldspar

Interstitial matrix (clay-size):

6% Clay minerals

Cement:

35% Carbonate - more than 90% dolomite

Pore space - nil

Classification: Dolomitic sandstone (very fine sand)

Thin section number - 3976 Hand specimen No. G52

Location - 1318 feet above base

Description:

Colour - (a) fresh surface - medium light gray (N6)

(b) weathered surface - brownish gray (5YR4/1)

Structure - cross-laminated, laminations due to partings of carbonaceous material and/or pyrite.

Texture - clastic, very fine sand, less commonly fine sand to coarse silt (average 0.08 mm.), angular, to sub-angular, occasionally sub-rounded to rounded, very angular coarse silt, very ill-sorted, well cemented, loosely packed, no porosity.

Composition:

Main components:

45% Quartz - very fine sand to coarse silt common, fine sand less common, average size being 0.08 mm., angular to sub-angular, rarely sub-rounded to rounded, contacts very rare, quartz grains being separated by carbonate content, occasionally one or two contacts, very minute irregular dusty inclusions present, but very rare, straight extinction, strained grains less than 5%.

Varietal minerals ($>$1%):

8% Carbonaceous material

2% Hematite

Accessory minerals ($\leqslant$1%):

Muscovite, zircon, tourmaline, plagioclase feldspar rutile

Interstitial matrix (clay-size):

9% Clay minerals

Cement:

35% Carbonate - more than 90% dolomite (by X-ray)

Pore space - nil

Classification: Dolomitic sandstone (very fine sand).

Spray River Formation, Whitehorse Member (Banff Area)

Thin section number - 3977 Hand specimen No. G53

Location - 1351 feet above base

Description:

Colour - (a) fresh surface - light gray (N7)

(b) weathered surface - light brownish gray (5YR6/1)

Structure - none apparent

Texture - rhomb, fine sand to coarse silt, average size being 0.10 mm.

Composition:

Varietal minerals (>1%):

5% Quartz - very fine sand to coarse silt, average size 0.055 mm., angular to sub-angular, minute dusty rare inclusions, straight extinction, contacts none.

Accessory minerals (≤1%):

Muscovite, pyrite

Interstitial matrix (clay-size):

2% Clay minerals

Cement:

92% Carbonate, shows polysynthetic twinning - 50.5% dolomite, 49.5% calcite (by X-ray)

Pore space - nil

Classification: Calcitic dolomite

Special feature: Originally formed from lime-mud, now altered due to diagenetic charges.

Thin section number - 3978 Hand specimen No. G56

Location - 1452 feet above base

Description:

Colour - (a) fresh surface - grayish yellow (5Y8/4)

(b) weathered surface - moderate yellow (5Y7/6)

Structure - none apparent

Texture - clastic, fine sand to very fine sand and coarse silt (average size 0.13 mm.), sub-angular to sub-rounded, rare rounded and occasionally well-rounded fine and very fine sand, angular to sub-rounded coarse silt, very ill-sorted, loosely packed, 1-2% porosity.

Composition:

Main components:

45% Quartz - fine sand to very fine sand and coarse silt, average size being 0.13 mm., commonly sub-angular to sub-rounded, rarely rounded and very rarely well-rounded quartz grains of fine and very fine sand size, contains rare grains being separated by carbonate cement, very small irregular dusty inclusions, but rare.

2% Chert and microquartzite - very fine sand size, sub-angular

Accessory minerals ($\leqslant$1%):

Hematite, plagioclase feldspar, microcline, tourmaline, zircon, rutile

Interstitial matrix:

12% Clay minerals

Cement:

40% Carbonate - 98% calcite, 2% dolomite (by X-ray)

Pore space - 1-2%

Classification: Calcitic orthoquartzite

Thin section number 3979 Hand specimen No. G58

Location - 1537 feet above base

Description:

Colour - (a) fresh surface - light bluish gray (5B7/1)

(b) weathered surface - dark yellowish orange (10YR6/6)

Structure - none apparent

Texture - medium to fine silt average .008 mm., 5% vuggy porosity, 0.06 mm. vugs, well-cemented.

Composition:

Varietal minerals (>1%):

5% Quartz - coarse silt, average 0.03 mm., very angular to angular.

Accessory minerals (≤1%):

Hematite, muscovite

Cement:

94% Carbonates - more than 90% dolomite (by X-ray)

Pore space - 5%

Classification: Dolomite

Spray River Formation, Sulphur Mountain Member (Cadomin Area)

Thin section number - 3980 Hand specimen No. S.M. 1

Location - 30 feet above base i.e. contact of Rundle Limestone and Spray River formation

Description:

Colour - (a) fresh surface - light bluish gray (5B7/1)

(b) weathered surface - light brownish gray (5YR6/1)

Structure - finely cross-laminated (laminations due to partings of carbonaceous material and/or pyrite).

Texture - clastic, very fine sand to coarse silt, average 0.055 mm., very angular to angular very fine sand and very angular coarse silt, poorly sorted, well-cemented, moderate to tight packing, no porosity.

Composition:

Main components:

45% Quartz - very angular to angular very fine sand, and very angular coarse silt, average size being 0.055 mm., moderate to tightly packed, one contact common, two contacts rare, dusty irregular inclusions rare, straight extinction, a few grains strained about 2%.

Varietal Minerals ($>$1%):

6% Carbonaceous material

3% Hematite

Accessory minerals ($\leqslant$1%):

Pyrite, muscovite, tourmaline, zircon

Interstitial matrix (clay size):

5% Clay minerals

Cement:

40% Carbonate - more than 90% dolomite (by X-ray)

Pore space - nil

Classification: Dolomitic siltstone.

Thin section number - 3981 Hand specimen No. S.M. 3

Location - 119 feet above base

Description:

Colour - (a) fresh surface - medium gray (N5)

(b) weathered surface - light olive gray (5Y6/1)

Structure - none apparent

Texture - clastic, very fine sand to coarse silt, average size .085 mm., some are about .21 mm., angular to sub-angular and occasionally sub-rounded very fine sand, and angular to sub-angular coarse silt, poorly sorted, about 3% porosity, moderate to loosely packed.

Composition:

Main components:

45% Quartz - angular to sub-angular and occasionally sub-rounded fine sand and angular coarse silt, the average size range being 0.085 mm., but some grains go up to 0.21 mm., one contact, rarely two, grains being separated by carbonate content, straight extinction, rarely strained grains.

Varietal minerals ($>$1%):

6% Carbonaceous material

4% Hematite

Accessory minerals ($\leqslant$1%):

Pyrite, muscovite, zircon, tourmaline

Interstitial matrix (clay-size):

9% Clay minerals

Cement:

35% Carbonate - more than 90% dolomite (by X-ray)

Pore space - 3%

Classification: Dolomitic sandstone (very fine sand)

Thin section number - 3982 Hand specimen No. S.M. 6

Location-181 feet above base

Description:

Colour - (a) fresh surface - medium bluish gray (5B5/1)

(b) weathered surface - light olive gray (5Y6/1)

Structure - none apparent

Texture - clastic, very fine sand to coarse silt, average size 0.055 mm., very angular to angular very fine sand and very angular coarse silt, very ill-sorted, well-cemented, loosely packed, no porosity.

Composition:

Main components:

25% Quartz - very angular to angular, very fine sand and very angular coarse silt, average size range 0.055 mm., no contacts, grains separated by carbonate content, straight extinction, rare irregular minute dusty inclusions.

Varietal minerals ($>$1%):

4% Carbonaceous material

3% Hematite

2% Pyrite

Accessory minerals ($\leqslant$1%):

Muscovite, zircon, tourmaline

Interstitial matrix (clay-size):

10% Clay minerals

Cement:

55% Carbonate - more than 90% dolomite (by X-ray)

Pore space - nil

Classification: Silty dolomite.

Thin section number - 3983

This thin section is of the same hand specimen i.e S.M. 6, as is the slide No. 3982, but this section is not covered with cover-glass. For description, see thin section No. 3982.

Thin section number - 3984 Hand specimen No. S.M. 7

Location - 349 feet above base

Description:

Colour - (a) fresh surface - very light gray (N8)

(b) weathered surface - dusky yellow (5Y6/4)

Structure - none apparent

Texture - rhombs, very fine to coarse silt, average size 0.05 mm., occasionally go up to 0.10 mm.

Composition:

Varietal minerals (>1%):

1% Quartz - coarse silt size, very angular, grains separated by carbonate content.

1% Pyrite

1% Hematite

Cement:

97% Carbonate - more than 90% dolomite (by X-ray)

Pore space - 15%

Classification: Dolomite.

Thin section number - 3985 Hand specimen No. S.M. 9

Location - 375 feet above base

Description:

Colour - (a) fresh surface - medium bluish gray (5B5/1)

(b) weathered surface - light brownish gray (5YR6/1)

Structure - none present

Texture - clastic, very fine sand to coarse silt, average size being 0.055 mm., very angular to angular, very fine sand and very angular coarse silt, poorly sorted, well-cemented, loosely packed, no porosity.

Composition:

Main components:

35% Quartz - very angular to angular very fine sand and very angular coarse silt, average size of grain 0.055 mm., contacts very rare, occasionally one, straight extinction.

Varietal minerals ($>$1%):

6% Carbonaceous material

5% Hematite

Accessory minerals ($\leqslant$1%):

Muscovite, pyrite, tourmaline, zircon

Interstitial matrix (clay-size):

8% Clay minerals

Cement:

45% Carbonate - more than 90% dolomite (by X-ray)

Pore space - nil

Classification: Silty dolomite.

Thin section number - 3986 Hand specimen No. S.M. 10

Location - 405 feet above base

Description:

Colour - (a) fresh surface - light gray (N7)

(b) weathered surface - brownish gray (5YR4/1)

Structure - none apparent

Texture - coarse to medium silt size

Composition:

Accessory minerals ($\leqslant$1%):

Quartz - coarse to medium silt size

Hematite

Pyrite

Cement:

99% Carbonate - more than 90% dolomite (by X-ray)

Pore space - nil

Classification: Dolomite.

Thin section number - 3987 Hand specimen No. S.M. 11

Location - 492 feet above base

Description:

Colour - (a) fresh surface - pale red purple (5RP6/2)

(b) weathered surface - light brown (5YR6/4)

Structure - none apparent

Texture - clastic, very fine sand and coarse to medium silt, average size 0.055 mm., angular to sub-angular very fine sand and very angular coarse to medium silt, ill-sorted, well-cemented, loosely packed, scattered vugs, about 3% porosity.

Composition:

Main components:

20% Quartz - very fine sand and coarse to medium silt average size being 0.055 mm., angular to sub-angular very fine sand and very angular coarse silt, contacts none, grains separated by carbonate content, dusty minute irregular inclusions but rare.

10% Hematite

<u>Varietal minerals (>1%)</u>:

1% Carbonaceous material

1% Muscovite

<u>Accessory minerals (<1%)</u>:

Pyrite, tourmaline, zircon

<u>Interstitial matrix (clay-size)</u>:

7% Clay minerals

<u>Cement</u>:

60% Carbonate - more than 90% dolomite (by X-ray)

Pore-space - 3%

<u>Classification</u>: Hematitic silty dolomite.

Spray River Formation, Whitehorse Member (Cadomin Area)

<u>Thin section number</u> 3988 Hand specimen No. WH.1

<u>Location</u> - 569 feet above base

<u>Description</u>:

Colour - (a) fresh surface - light bluish gray (5G8/1)

(b) weathered surface - very light gray (N8)

Structure - none apparent

Texture - clastic, very fine sand to coarse silt, average size being 0.056 mm., very angular to angular very fine sand and very angular coarse silt, poorly sorted, well-cemented, loosely packed, no porosity.

<u>Composition</u>:

<u>Main components</u>:

20% <u>Quartz</u> - very angular to angular very fine sand and very

angular coarse silt, average size 0.056 mm., no contacts, grains separated by carbonate content, irregular dusty inclusion present but rare, straight extinction.

Varietal minerals ($>1\%$):

1% Pyrite

1% Hematite

Accessory minerals ($\leqslant 1\%$):

Muscovite, tourmaline, zircon, plagioclase feldspar

Interstitial matrix (clay-size):

12% Clay minerals

Cement:

65% Carbonate - more than 90% dolomite (by X-ray)

Pore space - nil

Classification: Silty dolomite.

Thin section number - 3989 Hand specimen WH.2

Location - 687 feet above base

Description:

Colour - (a) fresh surface - pale red purple (5RP6/2)

(b) weathered surface - light brownish gray (5YR6/1)

Structure - none apparent

Texture - clastic, very fine sand and coarse to medium silt, average size being 0.05 mm., very angular to angular very fine sand and very angular coarse to medium silt, poorly sorted, loosely packed, 3% porosity.

Composition:

Main components:

43% Quartz - very fine sand and coarse to medium silt, average

size 0.05 mm., very angular to angular very fine sand and very angular coarse to medium silt, no contacts, grains being separated by carbonate content, straight extinction, irregular dusty inclusions presnet but rare.

10% Hematite

Accessory minerals ($\leqslant$1%):

Muscovite, pyrite, tourmaline, zircon

Interstitial matrix (clay-size):

6% Clay minerals

Cement:

40% Carbonate - more than 90% dolomite (by X-ray)

Pore space - 3%

Classification: Hematitic dolomitic siltstone.

Thin section number - 3990 Hand specimen No. 3 WH

Location - 702 feet above base

Description:

Colour - (a) fresh surface - pale red purple (5RP6/2)

(b) weathered surface - light brownish gray (5YR6/1)

Structure - none apparent

Texture - clastic, very fine sand and coarse silt, average size in the order .02 mm., angular to sub-angular very fine sand and very angular silt, very ill-sorted, loosely packed, well-cemented, no porosity.

Composition:

Main components:

20% Quartz - very fine sand and coarse silt, average size 0.02 mm., very fine sand angular to sub-angular, silt size grains very angular, no contacts, grains

separated by carbonate content, straight extinction, a few strained grains, less than 3%.

Varietal minerals (>1%):

2% Hematite

1% Pyrite

Accessory minerals (⩽1%):

Muscovite, tourmaline, zircon

Interstitial matrix (clay-size):

11% Clay minerals

Cement:

65% Carbonate - more than 90% dolomite

Pore space - nil

Classification: Silty dolomite.

Thin section number - 3991 Hand specimen No. WH.4

Location - 717 feet above base

Description:

Colour - (a) fresh surface - pale purple (5P6/2)

(b) weathered surface - light brownish gray (5YR6/1)

Structure - none apparent

Texture - clastic, very fine sand and coarse silt average size being 0.02 mm., angular to sub-angular very fine sand and very angular coarse silt, ill-sorted, loosely packed, 2% porosity.

Composition:

Main components:

10% Quartz - very fine sand to coarse silt, average size 0.02 mm., angular to subangular very fine sand and very angular

coarse silt, no contacts, grains separated by carbonate cement, straight extinction, a few grains less than 3% strained.

Varietal minerals ($>$1%):

2% Carbonaceous material

1% Hematite

Accessory minerals ($\leqslant$1%):

Pyrite, tourmaline, zircon, muscovite

Interstitial matrix (clay-size):

13% Clay minerals

Cement:

73% Carbonate - more than 90% dolomite (by X-ray)

Pore space - 2%

Classification: Silty dolomite.

Thin section number - 3992 Hand specimen WH.5

Location - 732 feet above base

Description:

Colour - (a) fresh surface - pale purple (5P6/2)

(b) weathered surface - light brownish gray (5YR6/1)

Structure - none apparent

Texture - clastic, very fine sand to coarse silt, average size being 0.05 mm., sub-angular to sub-rounded very fine sand and very angular to angular silt, very ill-sorted, loosely packed, 4% porosity.

Composition:

Main components:

43% Quartz - very fine sand to coarse silt, average size 0.05 mm., occasionally 0.10 mm., sub-angular to sub-rounded very fine sand, and angular coarse silt, no contacts, grains separated by carbonate content, minute irregular dusty inclusions, though rare, straight extinction, strained grains rare in the order of 3%.

10% Hematite

Accessory minerals ($\leqslant$ 1%):

Muscovite, tourmaline, zircon, rutile, plagioclase feldspar

Interstitial matrix (clay-size):

6% Clay minerals

Cement:

40% Carbonate - more than 90% dolomite (by X-ray)

Pore space - 4%

Classification: Hematitic dolomitic siltstone.

Thin section number - 3993 Hand specimen No. WH.6

Location - 744 feet above base

Description:

Colour - (a) fresh surface - very light gray (N8)

(b) weathered surface - yellowish gray (5Y8/1)

Structure - vague traces of bedding

Texture - clastic, fine to very fine sand and coarse silt, average size 0.10 mm., fine to very fine sand sub-angular to rounded, coarse silt angular to sub-angular, very ill-sorted, moderate to loosely packed, 2% porosity.

Composition:

Main components:

30% Quartz - very fine sand and coarse silt, average about 0.085 mm., some grains go up to 0.42 mm., sub-angular to rounded rarely well-rounded, contacts commonly one, occasionally two or three, irregular dusty inclusion present though very rare, straight extinction, strained grains very rare, less than 2%.

3% Chert and Microquartzite - fine sand to very fine sand, average size in the order 0.09 mm., rounded to well-rounded.

Rock fragments:

20% Mudstone - coarse to medium to fine to very fine sand, average size being 0.21 mm., rounded to well-rounded.

Accessory minerals ($\leqslant$ 1%):

Hematite, pyrite, mica, tourmaline, zircon, plagioclase feldspar

Interstitial matrix:

14% Clay minerals

Cement:

32% Carbonate - more than 90% dolomite (by X-ray)

Pore space - 2%

Classification: Dolomitic protoquartzite.

Thin section number - 3994 Hand specimen No. WH.9

Location - 780 feet above base

Description:

Colour - (a) fresh surface - light bluish gray (5B7/1)

(b) weathered surface - moderate yellow (5Y7/6)

Structure - none apparent

Texture - coarse to medium silt

Composition:

Varietal minerals ($>1\%$):

2% Quartz - coarse to medium silt.

Accessory minerals ($\leqslant 1\%$):

Hematite, pyrite

Cement:

97% Carbonate - more than 90% dolomite

Pore space - nil

Classification: Dolomite

Thin section number - 3995 Hand specimen No. WH.12

Location - 824 feet above base

Description:

Colour - (a) fresh surface - light gray (N7)

(b) weathered surface - light brown (5YR6/4)

Structure - none apparent

Texture - clastic, very fine to fine sand, average size being 0.11 mm., sub-angular to sub-rounded or rounded, well-sorted, loosely packed, well-cemented, no porosity.

Composition:

Main components:

45% Quartz - very fine to fine sand, average size in the order of 0.11 mm., angularity ranging from sub-angular grains to rounded grains, contacts rare one, grains separated by carbonate content, straight extinction, occasional strained grains, less than 2%.

2% <u>Chert and microquartzite</u> - very fine sand, average 0.06 mm., sub-angular to sub-rounded.

<u>Accessory minerals ($\leqslant$1%)</u>:

Microcline, tourmaline, zircon, muscovite

<u>Interstitial matrix</u>:

12% Clay minerals

<u>Cement</u>:

40% Carbonate - more than 90% dolomite (by X-ray)

Pore space - nil

<u>Classification</u>: Dolomitic orthoquartzite.

APPENDIX C

Determination of Calcite/Dolomite Ratios

A sample each of calcite and dolomite was selected, crushed separately down to fragments between one and two millimeters, then ground manually in an agate mortar. The ground samples were passed through a series of U.S. Standard Sieves and the -140 +230 fractions of each sample retained.

In order to ensure that the specimens of calcite and dolomite were pure, a sample of each was first X-rayed. The mounts for X-raying were prepared as follows:

(1) Petrographic glass-slides were covered with adhesive tape, except for a space one centimeter square in the centre of the slide.

(2) Enough -140 +230 mesh fraction (0.105-0.062 mm.) of the sample was placed in the open space to fill it even with the top of the adhesive tape border.

(3) The powdered sample was fixed to the slide by using a solution of acetone with household cement (a few drops of household cement per ounce of acetone).

X-ray patterns were run on the mounts using copper radiation, geiger-counter pick-up and Brown recorder. The samples gave pure calcite and dolomite patterns respectively, indicating that the samples were suitable for preparing standard mixtures. Accordingly, calcite and dolomite samples were weighed accurately, in powdered form, with an electric balance in the proportion of 75% calcite, 25% dolomite,

50% calcite, 50% dolomite, 25% calcite, 75% dolomite and 10% calcite, 90% dolomite to a total of 400 grams of each mixture. Homogeneous mixtures were made by stirring the two components together in a medium of alcohol for at least a half-hour and allowing the mixture to dry at room temperature.

To maintain equal quantities in the mounts, a 4 millimeter diameter hole was bored to about an equal depth in a glass-rod of 5 millimeter diameter, and this employed as a measure. Two mounts of each mixture were prepared. One pattern was run on each original mount, followed by a re-run after re-puddling the mixture. This method was employed to check the effect, if any, of variation in mounting technique. No significant variation in pattern was produced in the re-runs.

In this manner, sixteen patterns were run. The ratios of measured areas under the strongest peak ($^{d}104$) in the calcite and dolomite patterns were plotted against per cent dolomite of total calcite and dolomite.

Calculation of Standard Curve of Dolomite Percentages

The Standard Curve was prepared by measuring areas under the strongest peaks $^{d}(104)$ for calcite and dolomite in patterns run on mixtures prepared as described on pages 105-106. The patterns were run at one degree per minute with scale factor of (32), multiplier (1) and time constant 4 seconds.

The measured areas for the various prepared mixtures are given below:

75% Calcite and 25% Dolomite

Areas under the $^{d}(104)$ peak

Mount 1

First Run		Second Run	
Calcite	39.25 sq. units	Calcite	58.0 sq. units
Dolomite	23.50 sq. units	Dolomite	27.0 sq. units
Ratio (dolomite/calcite)	0.59	Ratio (dolomite/calcite)	0.465

Mount 2

First Run		Second Run	
Calcite	36.75 sq. units	Calcite	60.25 sq. units
Dolomite	20.50 sq. units	Dolomite	31.75 sq. units
Ratio (dolomite/calcite)	0.56	Ratio (dolomite/calcite)	0.52

50% Calcite 50% Dolomite

Mount 1

First Run		Second Run	
Calcite	32.75 sq. units	Calcite	50.25 sq.units
Dolomite	41.50 sq. units	Dolomite	63.50 sq.units
Ratio (dolomite/calcite)	1.28	Ratio (dolomite/calcite)	1.26

Mount 2

First Run		Second Run	
Calcite	39.75 sq. units	Calcite	48.32 sq.units
Dolomite	51.25 sq. units	Dolomite	62.40 sq.units
Ratio (dolomite/calcite)	1.25	Ratio (dolomite/calcite)	1.29

25% Calcite 75% Dolomite

Mount 1

First Run		Second Run	
Calcite	16.75 sq. units	Calcite	16.75 sq.units
Dolomite	46.25 sq. units	Dolomite	42.75 sq.units
Ratio (dolomite/calcite)	2.80	Ratio (dolomite/calcite)	2.60

Mount 2

First Run		Second Run	
Calcite	17.25 sq.units	Calcite	18.60 sq.units
Dolomite	45.90 sq.units	Dolomite	50.25 sq.units
Ratio (dolomite/calcite)	2.70	Ratio (dolomite/calcite)	2.68

10% Calcite 90% Dolomite

Mount 1

First Run		Second Run	
Calcite	8.25 sq. units	Calcite	8.40 sq.units
Dolomite	44.25 sq. units	Dolomite	46.50 sq.units
Ratio (dolomite/calcite)	5.5	Ratio (dolomite/calcite)	5.75

Mount 2

First Run		Second Run	
Calcite	7.75 sq.units	Calcite	8.60 sq.units
Dolomite	43.80 sq.units	Dolomite	48.26 sq.units
Ratio (dolomite/calcite)	5.65	Ratio (dolomite/calcite)	5.68

TABLE 4

Tabulation of Dolomite/Calcite Ratios

in Spray River Section Near Banff, Alta.

Sr. No.	Specimen No.	Height above base in feet	Areas in square units Calcite	Dolomite	Ratio (dolo/ calcite)	Per cent dolomite content
1	G(1)	00.00	3.25	55.00	18.00	> 90
2	G(2)	35.00	7.50	13.00	01.74	60
3	G(3)	70.00	4.50	19.25	04.27	85
4	G(4)	100.00	4.00	8.25	02.12	67
5	G(5)	152.00	2.50	37.00	14.80	> 90
6	G(6)	165.00	3.50	32.50	09.28	> 90
7	G(7)	177.00	1.45	32.50	22.40	> 90
8	G(8)	185.00	17.75	31.75	01.78	61
9	G(9)	245.00	10.50	20.00	01.90	63.5
10	G(10)	340.00	50.50	15.25	0.302	14.5
11	G(11)	450.00	27.75	10.75	0.38	17.0
12	G(12)	460.00	2.75	29.50	10.70	> 90
13	G(13)	473.00	4.00	28.75	7.18	> 90
14	G(14)	478.00	53.25	24.00	0.453	18.5
15	G(15)	483.00	80.50	17.00	0.211	10
16	G(16)	488.00	109.25	11.00	0.10	04.5
17	G(17)	506.00	2.75	3.50	1.27	50
18	G(18)	519.00	51.50	15.00	0.29	13.5
19	G(19)	530.00	46.25	12.25	0.26	12.0
20	G(20)	550.00	4.00	32.50	8.125	> 90
21	G(21)	907.00	14.00	23.80	1.70	61

Tabulation of Dolomite/Calcite Ratios

in Spray River Section Near Banff, Alta. (continued)

Sr. No.	Specimen No.	Height above base in feet	Areas in square units Calcite	Dolomite	Ratio (dolo/ calcite)	Per cent dolomite content
22	G(22)	932.00	17.25	19.25	1.12	46.0
23	G(23)	960.00	71.00	7.50	0.160	07.0
24	G(24)	999.00	95.50	18.00	0.188	08.0
25	G(25)	1015.00	16.25	25.50	1.620	58.0
26	G(26)	1030.00	10.75	30.25	2.95	77.0
27	G(27)	1036.00	12.25	34.75	2.83	76.25
28	G(28)	1051.00	05.00	37.50	7.50	>90.0
29	G(29)	1066.00	4.00	42.75	10.98	>90
30	G(30)	1078.00	15.50	7.00	0.47	21
31	G(31)	1086.00	38.4	5.00	0.13	06.5
32	G(32)	1094.00	24.75	44.00	1.78	61
33	G(33)	1101.00	137.50	17.00	0.124	05
34	G(34)	1109.00	152.00	19.50	0.128	05.5
35	G(35)	1125.00	06.00	53.25	8.80	>90.0
36	G(36)	1136.00	02.00	65.75	32.87	>90.0
37	G(37)	1146.00	1.00	27.00	27.00	>90.0
38	G(38)	1157.00	No distinct peak	24.25	∞	∞ taken as 90%
39	G(39)	1166.00	Do.	22.5	∞	Do.
40	G(40)	1180.00	Do.	126.00	∞	Do.
41	G(41)	1185.00	17.50	78.00	4.58	>90
42	G(42)	1196.00	3.75	39.00	12.78	>90

Tabulation of Dolomite/Calcite Ratios

in Spray River Section Near Banff, Alta. (continued)

Sr. No.	Specimen No.	Height above base in feet	Areas in square units Calcite	Dolomite	Ratio (dolo/ calcite)	Per cent dolomite content
43	G(43)	1204.00	4.75	29.50	6.22	>90
44	G(44)	1214.00	No distinct peak	46.50	∞	∞ taken as 90%
45	G(45)	1226.00	Do.	83.50	∞	Do.
46	G(46)	1231.00	14.00	38.00	2.34	70.5
47	G(47)	1236.00	No distinct peak	81.00	∞	∞ taken as 90%
48	G(48)	1250.00	Do.	42.00	∞	Do.
49	G(49)	1277.00	Do.	27.00	∞	Do.
50	G(50)	1282.00	18.00	42.00	2.33	70
51	G(51)	1313.00	No distinct peak	67.00	∞	∞ taken as 90%
52	G(52)	1318.00	5.5	43.75	7.5	>90
53	G(53)	1351.00	96.25	113.75	1.17	50.5
54	G(54)	1371.00	5.50	157.5	28.60	>90
55	G(55)	1385.00	38.60	1.0	0.03	7
56	G(56)	1452.00	116.75	6.5	0.04	2
57	G(57)	1487.00	2.50	177.5	71.00	>90
58	G(58)	1537.00	6.50	205.5	31.53	>90

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TABLE 5

Tabulation of Dolomite/Calcite Ratios

In Spray River Section Near Cadomin, Alta.

Sr. No.	Specimen No.	Height above base in feet	Areas in square units Calcite	Dolomite	Ratio	Per cent dolomite content
1	S.M.(1)	30.00	3.00	36.00	12.00	>90
2	S.M.(2)	89.00	No distinct peak	33.75	∞	∞ taken as 90%
3	S.M.(3)	119.00	Do.	32.00	∞	Do.
4	S.M.(4)	134.00	Do.	38.75	∞	Do.
5	S.M.(5)	155.00	1.50	50.50	33.70	>90
6	S.M.(6)	181.00	No. distinct peak	28.50	∞	∞ taken as 90%
7	S.M.(7)	349.00	22.00	166.50	7.57	>90
8	S.M.(8)	350.00	No distinct peak	37.50	∞	∞ taken as 90%
9	S.M.(9)	375.00	Do.	39.25	∞	Do.
10	S.M.(10)	405.00	Do.	178.75	∞	Do.
11	S.M.(11)	492.00	Do.	165.75	∞	Do.
12	S.M.(12)	524.00	4.50	157.25	34.9	>90
13	W.H.(1)	569.00	No distinct peak	56.60	∞	∞ taken as 90%
14	W.H.(2)	687.00	Do.	58.00	∞	Do.
15	W.H.(3)	702.00	Do.	106.50	∞	Do.
16	W.H.(4)	717.00	5.50	156.8	28.50	>90

Tabulation of Dolomite/Calcite Ratios

In Spray River Section Near Cadomin, Alta. (continued)

Sr. No.	Specimen No.	Height above base in feet	Areas in square units Calcite	Dolomite	Ratio	Per cent dolomite content
17	W.H.(5)	732.00	No distinct peak	77.50	∞	∞ taken as 90%
18	W.H.(6)	744.00	Do.	60.10	∞	Do.
19	W.H.(7)	764.00	11.50	163.75	14.80	>90
20	W.H.(8)	772.00	08.00	20.50	2.50	72.5
21	W.H.(9)	780.00	No distinct peak	205.60	∞	∞ taken as 90%
22	W.H.(10)	788.00	Do.	201.75	∞	Do.
23	W.H.(11)	794.00	12.00	115.25	9.58	>90
24	W.H.(12)	824.00	14.00	106.00	7.5	>90